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NOTICE

The ROYAL METEOROLOGICAL SOCIETY does not accept any responsibility for the views and opinions expressed by individual writers in the *Quarterly Journal*.

ERRATA.

Page 73, *line* 17—220d and 286d *should read* 220a and 286a.

Page 198, *the column headed*—Pressure e_4, *for* August 0.29 *read* .029.

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ON THE ASSOCIATION OF THE DIURNAL VARIATION OF ELECTRIC POTENTIAL GRADIENT IN FINE WEATHER WITH THE DISTRIBUTION OF THUNDERSTORMS OVER THE GLOBE.

By F. J. W. WHIPPLE, Sc.D., F.R.Met.Soc.

[Manuscript received October 8, 1928—Read November 21, 1928.]

1. INTRODUCTION.

In fine weather the diurnal variation of electric potential gradient shows at most places a double oscillation in the course of the twenty-four hours. At Kew Observatory, for example, the potential gradient is high in the evening at 20h. and in the morning at 9h.; it is low in the early morning and in the early afternoon. The two maxima are about equal, but the morning minimum is the lower. In the polar regions however where, especially in winter, the meteorological elements change but little during the day, the variation of potential gradient is of a simpler type with only one maximum and one minimum.

The observations at seven places, four in the Arctic regions and three in the Antarctic, were compared by Hoffmann when he published[1] the results obtained in Spitzbergen in 1913-14. Hoffmann noticed that when the observations at the several stations were referred to local time the hours at which the maxima and minima occurred differed widely, but when he referred the daily variations at all the stations to universal time he found that all the principal maxima and minima agreed.

Shortly afterwards S. J. Mauchly, of the Carnegie Institution, published[2] his discussion of the results obtained during the cruises of the "Carnegie" and showed that the diurnal variation of potential gradient was of the same simple type. Moreover, Mauchly's analysis of the readings at observatories in various parts of the world indicated that there was some general cause tending to produce a simple synchronous oscillation even though it might be modified by local conditions. Additional support for Mauchly's generalization is provided by the observations made by Sverdrup during the cruise of the "Maud" in the Arctic Ocean.[3] All these observations of the potential gradient agree in showing a maximum at about 18h. by Greenwich time and a minimum at about 4h., the drop being more rapid than the rise.

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[1] K. Hoffmann. *Beitr. Physik Atmosph., Leipzig*, **11**, 1923, p. 1. Apparently it was consideration of the fact that the mean potential gradient was highest at the same season (the southern summer) in both hemispheres that led Hoffmann to the idea that direct local solar influence was unimportant and that the diurnal variation might be governed by a universal cause.

[2] S. J. Mauchly. *Terr. Mag., Baltimore*, **28**, 1923, p. 61; *Washington, Res. Dep. Terr. Mag., Carnegie Inst.*, **5**, 1926, p. 385. The first evidence for the simultaneous wave of potential gradient over the oceans was published by Mauchly in 1921. *Physic. Rev.*, **18**, 1921, pp. 161, 477.

On reading Mauchly's paper it occurred to me that the world-wide daily oscillation of potential gradient might provide a valuable test of Wilson's theory of the circulation of atmospheric electricity. It is well known that during fine weather, whilst potential gradient is positive, a current of positive electricity flows from the air to the earth and on the other hand that during rainfall, and especially during thunderstorms, the potential gradient is frequently negative and the current is reversed. According to Wilson's theory the total flux of electricity due to conduction currents, to lightning and to rain is zero. In other words, the ordinary potential gradient of fine weather is maintained by the operation of thunderstorms. The electricity generated in a thunderstorm is supposed to reach the Heaviside layer and to be conveyed through that layer to other parts of the world. In the fine weather regions a downward current is maintained.

It is a corollary from Wilson's theory that the air-earth current should fluctuate according to the number and intensity of the thunderstorms in progress. Now thunderstorms are frequent in the East Indies, in Central Africa and in South America. Moreover, on land the usual time for thunderstorms to occur is in the afternoon, and therefore the greatest number must be occurring when it is afternoon in the centre of the thunderstorm belt, say in the middle of Africa. That there was a rough agreement with the maximum in the potential gradient at polar and oceanic stations was brought out in a diagram published in the *Meteorological Magazine*.[4] The point required closer examination however and the principal object of the present investigation was to determine as precisely as might be possible the form of the diurnal variation of thunderstorm frequency. The earlier conclusion that Mauchly's results were in accordance with Wilson's theory has been confirmed. The calculations indicate that there is probably very little delay between the generation of electricity in thundery areas and the response in the potential gradient in fine weather regions. The latter part of the paper is devoted to some of the questions which arise when the flow of electricity is considered in more detail.

2. THE DISTRIBUTION OF THUNDERSTORMS.

As the basis of the discussion I have utilised three maps of the globe (on Mercator's projection) on which the number of days with thunder had been plotted at various points. These maps, which were used by Dr. Brooks in preparing his memoir, "The Distribution of Thunderstorms over the Globe,"[5] refer one to the six months April to September, another to the six months October to March and the third to the whole year. For each "10° square"

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[3] H. U. Sverdrup. *Washington, Res. Dep. Terr. Mag., Carnegie Inst.*, **6**, 1927, p. 425.

[4] F. J. W. Whipple. *Meteor. Mag., London*, **59**, 1924, p. 201. The agreement was noticed independently by A. Wigand, *Phys. Zs.*, **28**, 1927, p. 68.

[5] C. E. P. Brooks. *London, Meteor. Off., Geophys. Mem.*, No. 24, 1925.

between the latitudes 60°N. and 60°S. I estimated the proportion of land and the average number of days with thunder. By multiplying the latter number by the appropriate fraction a measure of the effectiveness of each "square" was obtained. These data were combined in threes, so giving the effectiveness of a rectangle covering 10° in latitude and 30° in longitude. The estimates based on the three maps were compared and brought into agreement. Then the necessary allowance was made for the varying size of the rectangles according to their distance from the equator. The results are shown in Tables I. and II. in which each entry represents the product of the land area in a "rectangle" and the average number of thunder days occurring over the land, the unit of area being the segment from pole to pole bounded by lines of longitude

TABLE I.—THE DISTRIBUTION OF LAND THUNDERSTORMS IN THE NORTHERN SUMMER. APRIL-SEPTEMBER.

			W.						E.			
	180° 150°	150° 120°	120° 90°	90° 60°	60° 30°	30° 0°	0° 30°	30° 60°	60° 90°	90° 120°	120° 150°	150° 180°
50°-60°N	.00	.07	.47	.21	.00	.06	.52	.75	.77	.62	.42	.00
40°-50°	—	.03	1.45	1.05	.00	.18	1.13	.66	.37	.00	.63	—
30°-40°	—	.01	1.72	1.14	—	.12	.14	.38	.12	.76	.12	—
20°-30°	—	—	1.21	.31	—	.00	.00	.10	1.24	1.60	.03	—
10°-20°	—	—	.74	.50	—	.23	.53	.59	.70	1.06	.39	—
0°-10°N	—	—	—	2.00	.43	.39	3.21	1.09	.13	.73	.39	—
0°-10° S	—	-	—	1.04	1.27	—	1.74	.09	—	1.06	.81	.02
10°-20°	—	—	—	.22	1.04	—	.56	.15	—	—	.07	—
20°-30°	—	—	—	.11	.34	—	.37	.17	—	.02	.00	.02
30°-40°	—	—	—	.16	.20	—	.05	—	—	.05	.21	.07
40°-50°	—	—	—	.03	—	—	—	—	—	—	.00	.01
50°-60°S	—	—	—	.00	—	—	—	—	—	—	—	—
	0.0	0.1	5.6	6.8	3.3	1.0	8.3	4.0	3.3	5.9	3.1	0.1

TABLE II.—THE DISTRIBUTION OF LAND THUNDERSTORMS IN THE SOUTHERN SUMMER. OCTOBER-MARCH.

			W.						E.			
	180° 150°	150° 120°	120° 90°	90° 60°	60° 30°	30° 0°	0° 30°	30° 60°	60° 90°	90° 120°	120° 150°	150° 180°
50°-60°N	.00	.00	.00	.00	.00	.02	.02	.00	.00	.00	.00	.00
40°-50°	—	.00	.04	.13	.00	.02	.08	.02	.00	.00	.03	—
30°-40°	—	.00	.31	.20	—	.05	.09	.20	.00	.03	.04	—
20°-30°	—	—	.21	.05	—	.00	.00	.07	.37	.29	.00	—
10°-20°	—	—	.17	.14	—	.11	.13	.16	.14	.37	.17	—
0°-10°N	—	—	—	2.35	.44	.26	2.29	.52	.10	1.12	.19	—
0°-10°S	—	—	—	1.86	2.73	—	3.50	1.50	—	1.26	1.25	.04
10°-20°	—	—	—	.84	3.10	—	3.92	1.23	—	—	1.12	—
20°-30°	—	—	—	.33	.98	—	1.59	.80	—	.11	.40	.08
30°-40°	—	—	—	.46	.27	—	.21	—	—	.04	.35	.10
40°-50°	—	—	—	.08	—	—	—	—	—	—	.01	.02
50°-60°S	—	—	—	.01	—	—	—	—	—	—	—	—
	0.0	0.0	0.7	6.4	7.5	0.5	11.8	4.5	0.6	3.2	3.5	0.2
The Year	0.0	0.1	6.3	13.2	10.8	1.5	20.1	8.5	3.9	9.1	6.6	0.3

30° apart. The sum of a column is therefore an estimate of the integral $\int N dS$ in which dS is an element of land surface, N is the frequency of thunder days and the integral is taken over all land between the latitudes ±60°.

There is considerable uncertainty about some of the entries in the tables as there are few parts of the globe for which information is adequate. The tables are reproduced to show the material utilized in the investigation, not as giving final values for the effectiveness of the individual areas. The entry .00 signifies that there is land in the rectangle but that thunderstorms are very rare. The dash signifies that there is practically no land in the rectangle.

As was to be expected the most conspicuous features of the tables are the preponderance of the thunderstorms of the tropics, the change in latitude from season to season and the absence of entries in the longitudes which correspond to the Pacific Ocean.

As to the exact significance of a day with thunder, there is inevitably some uncertainty as the statistics depend primarily on observations which may not have been made according to the accepted convention. In a country where thunderstorms are rare an observer will place on record a single peal of distant thunder. In a country where storms are frequent the distant ones are likely to be ignored. Thus, it is likely that the statistics minimise the contrast between the parts of the world with many storms and few.

The mean of the entries in the bottom line of Table I. is 3.46. The mean of the entries in the corresponding line of Table II. is 3.24. Now it is found that the total area of the land between 60°N. and 60°S. is .222 of the total area of the globe. It follows that in the northern summer the average number of thunderstorms heard at a place on land within that area is 15.6, whilst the average in the other half of the year is 14.6. The average for the whole year is therefore 30. For comparison we note that Brooks gives 25.2 as the annual average for a land station in the northern hemisphere and 43.8 as the corresponding average for the southern hemisphere.

Turning now to the times of day at which thunderstorms occur on land, we find that if places near the coast are ignored there is general agreement in all parts of the world. Statistics giving the numbers of storms hour by hour are not available for many places in the tropics. There is, however, an excellent series of observations for two stations in Travancore in the far south of India. These observations were made in the years 1853—1864, but they were not generally available until they were published[6] in 1898. The thunderstorm data were summarized[7] in the *Meteorologische Zeitschrift*, whence we quote the figures in the first three lines of the following table. The station at Agustia was 6,200 feet above sea-level.

The figures given for central Europe are taken from Hann.[8] It will be noticed that the time is divided somewhat differently, the Indian figures referring nominally to thunderstorms in progress at the specified hours, the European figures to thunderstorms heard

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[6] *Indian Met. Mem., Calcutta*, **10**, 1898.
[7] *Met. Zs., Braunschweig*, 1905, p. 175.
[8] *Lehrbuch der Meteorologie*, 2nd Ed., 1926, p. 693.

TABLE III.—RELATIVE FREQUENCY OF THUNDERSTORMS THROUGHOUT THE DAY

Hours.	1–2	3–4	5–6	7–8	9–10	11–12	13–14	15–16	17–18	19–20	21–22	23–24
Trevandrum -	6	5	4	1	1	2	13	25	16	13	8	6
Agustia -	3	3	0	0	2	3	15	36	22	9	5	2
Mean -	4.3	3.9	2.3	0.7	1.5	2.5	14.2	30.3	19.0	11.3	6.1	4.0

Hours.	0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24
Central Europe	2.9	2.5	2.1	1.9	2.5	7.1	15.3	21.0	19.3	13.0	8.5	3.9
Adopted for Globe	4	3	2	1	2	5	15	25	19	12	7	5

between the hours. The distinction is of little importance and I have taken the means with a slight adjustment as representative for the whole globe.

Now consider the thunderstorms in progress at a specified hour of universal time, say at Greenwich noon, and let us take the figures for the northern summer.

At places in the segment 0°—30°E. the local time is between 12h. and 14h. In that segment the expectation of land thunderstorms is 8.3 for the six months. Of the 8.3 the proportion 15 per cent. is to be credited to the interval 12h. to 14h. so that the effectiveness of the segment at that time may be measured by the product .15 × 8.3 or 1.245. Similarly at places in the segment 30°—60°E. the local time corresponding with Greenwich noon is between 14h. and 16h. and the contribution of this segment is .25 × 4.0 or 1.000. The contributions of the various segments are shown below.

TABLE IV.—EFFECTIVENESS OF LAND THUNDERSTORMS AT GREENWICH NOON.

Long. E.	" Effectiveness."	Long. W.	" Effectiveness."
0–30	8.3 × .15 = 1.245	150–180	0.0 × .04 = .000
30–60	4.0 × .25 = 1.000	120–150	0.1 × .03 = .003
60–90	3.3 × .19 = .627	90–120	5.6 × .02 = .112
90–120	5.9 × .12 = .708	60–90	6.8 × .01 = .068
120–150	3.1 × .07 = .217	30–60	3.3 × .02 = .066
150–180	0.1 × .05 = .005	0–30	1.0 × .05 = .050

Mean - = 0.342

What is the significance of the mean effectiveness 0.342?

It indicates[9] that if we had observation posts spaced uniformly over the globe, if to every post at sea or in the polar regions we credited a zero and to every post on the land the average number of thunderstorms heard within an hour of noon in the six months of the northern summer, then the general average for all the posts would be 0.342.

---

[9] This statement is not quite accurate; the fact that a thunderstorm may last several hours makes a precise statement in ordinary language difficult. It is also to be noted that the possibility of two storms occurring at the same place on the same day has been ignored in the argument.

If we confine attention to a single day in the northern summer we can say that the area over which land thunderstorms are heard within an hour of noon G.M.T. is .342/183 of the area of the whole globe. As the area of the globe is 5.12×10^8 km^2 this estimate is equivalent to 960,000 km^2. For comparison we note that a 10° square on the equator covers about 1,230,000 km^2.

The mean areas affected by thunderstorms have been computed in this way for each second hour of Greenwich mean time. The areas are given in the following schedule for the northern summer (April—September), for the southern summer (October—March) and for the year.

TABLE V.—DAILY VARIATION OF THUNDER AREAS. (LAND BETWEEN ± 60° LAT.) Unit = 10^4 km^2.

Hour G.M.T.	2	4	6	8	10	12	14	16	18	20	22	24
N. Summer...	47	46	63	80	86	96	101	91	95	104	92	66
S. Summer...	39	40	51	57	63	92	115	111	117	104	76	51
Year	43	43	57	68	75	94	108	101	106	104	84	59

To determine the total area affected by thunderstorms at any time we must allow for the thunderstorms at sea and in the regions north of 60°N. or south of 60°S. For this purpose we may accept Brooks's estimates[10] of the average number of days with thunder for the whole globe. These are 8.5 for the northern summer, 7.7 for the southern summer and 16.2 for the year. Now the contributions of the land thunderstorms in Tables I. and II. are 3.46 and 3.24 respectively, so that the contributions from the sea and the high latitudes are 5.04 in the northern summer and 4.46 in the southern. These contributions to the averages are made by 7/9 of the total area. It is therefore implied that at sea or in high latitudes the average number of thunderstorms is 6.5 in the northern summer and 5.7 in the southern, *i.e.*, 12.2 in the whole year.

The diurnal variation in the frequency of thunderstorms should, it might be thought, be easily determined from observations on board ship. The ship's logs give the observations for each watch of four hours and the number of watches in which thunder and lightning are reported can be counted. Few analyses of this sort have been published, however, and the only one covering a long period appears to be that of Meinardus, who discussed[11] the observations for the eastern part of the Indian Ocean. The distribution of the observations is given below; the entries are percentages of the total number of watches, 986, in which thunder occurred.

TABLE VI.

Watch.	0-4	4-8	8-12	12-16	16-20	20-24
Indian Ocean	22.5	15.3	11.4	13.0	16.4	21.4
Lighthouses in N.W. Scotland	22.1	15.1	12.9	12.2	16.6	21.1

The statistics[12] collected by Buchan for the thunderstorms observed from the lighthouses in N.W. Scotland are added for comparison.

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[10] *loc. cit.* No. 5, p. 157.

[11] *Ann. Hydr., Berlin,* **23,** 1895, p. 506.

[12] Copied by Meinardus from Sprung (*Lehrbuch der Meteorologie*, p. 359).

Meinardus was careful to include in his statistics only the occasions on which thunder was heard. This condition is of great importance. The statistics published by Köppen for the N. Atlantic show[13] that lightning alone is logged at least three times as often as lightning and thunder together. Unfortunately Köppen's tables do not discriminate between one watch and another. It is obvious, however, that distant lightning is more readily noticed in the night. One may go a step further, and say that thunder is also more likely to be logged by night than by day, simply because a brief thunderstorm is more likely to be noticed at night. The observer sees a flash and waits for the thunder, whereas by day he might miss both. There are two arguments which throw doubt on the type of diurnal variation found by Meinardus. The first is that any physical cause which would produce a maximum development of thunderstorms in the hours of darkness would be likely to be progressive. Just as on land, thunderstorms are more numerous in the afternoon than in the forenoon, so at sea the number of storms from 4 to 8 should be greater than the number between 20 and 24. Actually the statistics imply a symmetrical distribution on either side of midnight. The second argument depends on the likeness between the statistics given by Meinardus and by Buchan. The thunderstorms of N.W. Scotland occur in winter and are associated with the progress of cyclones. It is very unlikely that radiation has anything to do with such thunderstorms. They are storms in which there may be very few peals of thunder and they are therefore much more likely to pass unrecorded in the daytime than at night. If the apparent diurnal variation is merely observational in Scotland the same may well be true in the Indian Ocean.

In spite of these doubts as to the reality of the local diurnal variation in the frequency of thunderstorms over the open oceans, it would have been of interest to examine the distribution in longitude of the storms and to deduce the variation in the frequency of thunder throughout the 24 hours of Greenwich time. Unfortunately that cannot be done at present. No summary of marine observations of thunderstorms has yet been published for the Pacific, and in fact comparable figures are available only for parts of the Atlantic and of the Indian Ocean. With the growth of aerial navigation the importance of thunderstorms has increased and it may be hoped that information will be collected.

Meanwhile we can only regard the storms at sea as so well distributed in space and time that they are equally likely to occur at any hour by Greenwich time. Taking the estimate, admittedly not very reliable, found above for the average number of thunderstorms in the northern summer, we estimate that in that season the area over which thunderstorms occur at sea (or in high latitudes) within any interval of two hours is

$$\frac{5{\cdot}04}{12 \times 183} \times 5{\cdot}12 \times 10^8 \text{ km}^2$$
$$\text{or } 118 \times 10^4 \text{ km}^2.$$

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[13] *Ann. Hydr., Berlin*, **46**, 1918, p. 64.

The corresponding areas for the southern summer and the whole year are 105×10^4 km² and 111.5×10^4 km².

Adding these areas to those in the previous table we obtain the following estimates:—

TABLE VII.—DAILY VARIATION OF THUNDER AREAS (LAND AND SEA).
Unit = 10^4 km².

Hours G.M.T.	2	4	6	8	10	12	14	16	18	20	22	24
N. Summer ...	165	164	181	198	204	214	219	209	213	222	211	184
S. Summer ...	144	145	156	162	168	197	220	216	222	209	181	156
Year	155	155	169	180	186	205	219	213	217	215	196	170

It will be seen that the range of variation is the greater in the southern summer. The principal maximum is rather later in the northern summer than in the southern, but the time of the minimum is practically the same at both seasons.

3. POTENTIAL GRADIENT AND THUNDERSTORMS.

Turning now to the observations of potential gradient and confining our attention to statistics for regions in which the regular changes in the meteorological factors such as wind, temperature and humidity in the course of the day are small, we select four sets of data. Two of these are representative[14] of the observations at fixed stations in polar regions. For both of these we are indebted to Simpson. One series was obtained[15] at Karasjok in Lapland, a station which was chosen as the most northerly village in Europe not on the sea coast. The other station was at Cape Evans, the headquarters of Scott's last expedition.[16] There is one series of observations[17] on the oceans; these observations were made on the *Carnegie* and were the starting point of Mauchly's researches. The last set of observations to be published was obtained by Sverdrup[18] on the *Maud* during the drift of that vessel across the Arctic Ocean. The fogs which prevailed in the Arctic during the northern summer militated against electrical recording during that season. Thus we have all four sets of observations for one half of the year and only three sets for the other half.

In Tables VIII. and IX. the mean potential gradient for each hour is given as a percentage of the mean for the day. Sverdrup's and Mauchly's tables give means for the periods of 60 minutes centred at exact hours G.M.T., whilst Simpson's tables refer to the intervals from hour to hour. In dealing with Simpson's data for the Antarctic, etc., I have weighted his figures, which refer to "seasons" of three months, according to the number of observations. In dealing with the Lapland observations the mean for six months was found as half the sum of the values given for two periods of three months. The irregularities in the sequences of figures for the Antarctic are obviously due to the comparative rarity of suitable observations.

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[14] Other stations for which data are available are: Cape Thordsen and Ebeltofthafen, both in Spitzbergen; Danmarkshafen in Greenland; Petermann Island and Wandel Island in Antarctica; *cf.* Hoffmann. *Beitr. Physik. Atmosph., Leipzig*, **11**, 1924, p. 18.

[15] *London, Phil. Trans. R. Soc.*, 205 (A), 1905, p. 61.

[16] British Antarctic Expedition 1910-1913. *Meteorology*, Vol. 1, p. 302.

[17] *Washington, Res. Dept. Terr. Mag., Carnegie Inst.*, **5**, 1926, p. 385.

[18] *Washington, Res. Dept. Terr. Mag., Carnegie Inst.*, **6**, 1927, p. 425.

TABLE VIII.—The Daily Variation of Potential Gradient and of Thunderstorm Frequency in the Northern Summer.

G.M.T.	0	2	4	6	8	10	12	14	16	18	23	22	24
Potential Gradient (May-October) per cent of mean.													
Lapland 1904. Karasjok.		84, 78	75, 75	79, 88	96, 99	98, 91	89, 93	97, 101	102, 109	113, 119	127, 132	135, 119	103, 94
Oceans. 1915-21.		94, 90	88, 88	88, 90	93, 96	95, 94	92, 94	95, 97	104, 106	112, 115	120, 121	115, 111	106, 101
Antarctic 1911-12. Cape Evans		98, 95	95, 81	84, 93	89, 89	93, 102	96, 91	96, 101	97, 102	107, 106	106, 115	128, 121	109, 107
Thunderstorms (April-September) per cent. of mean.													
The Globe		83	82	91	99	103	107	110	105	107	111	106	92

TABLE IX.—The Daily Variation of Potential Gradient and of Thunderstorm Frequency in the Southern Summer.

G.M.T.	0	2	4	6	8	10	12	14	16	18	20	22	24
Potential Gradient (November-April) per cent of mean.													
Arctic Ocean Maud 1923-24		90, 86	85, 85	85, 87	88, 89	89, 90	96, 99	106, 112	115, 117	118, 119	119, 118	111, 104	99, 95
Lapland 1903-4. Karasjok		68, 59	55, 53	61, 77	82, 91	101, 113	112, 112	115, 112	112, 110	121, 135	141, 144	132, 132	100, 76
Oceans. 1915-21		86, 87	86, 85	87, 87	90, 92	90, 92	98, 105	111, 110	117, 115	112, 118	121, 112	110, 105	94, 87
Antarctic 1911-12 Cape Evans		81, 77	78, 73	83, 88	90, 89	95, 114	109, 106	107, 124	128, 115	119, 120	119, 115	108, 100	84, 79
Thunderstorms (October-March) per cent. of mean.													
The Globe		79	80	86	89	93	109	121	119	123	116	100	86

The general agreement between the four sets of observations is striking and fully justifies the statement that the changes in potential gradient from hour to hour are mainly due to a world-wide cause.

For comparison the thunderstorm areas of Table V. have also been reduced to percentages of their mean values. Inspection of the graphs (Figs. 1 and 2) shows that the concordance between the statistics of potential gradient and of thunderstorms is good. The clearly marked features of the march of potential gradient can be interpreted in terms of the geography of thunderstorms. The sequence of events is shown most clearly in the southern summer. Potential gradient is lowest when the sun is over the Pacific. The storms of the East Indies produce a slight rise at about 6h. G.M.T.

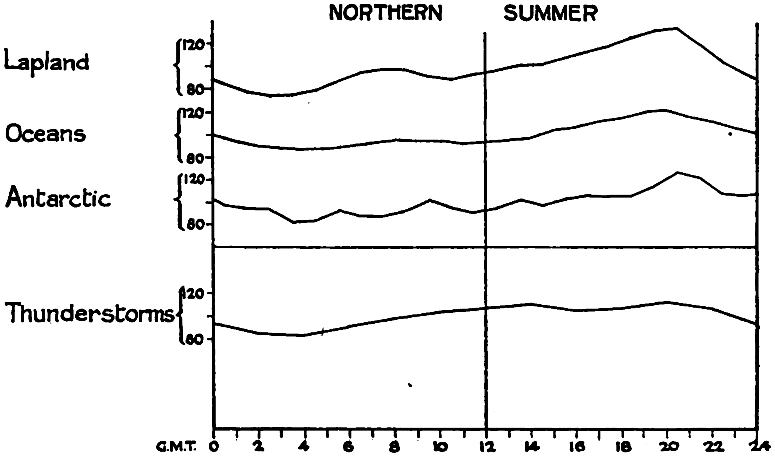

FIG. 1.—Diurnal Variation of Potential Gradient and of Thunderstorm Frequency in the Northern Summer. Percentages of mean values.

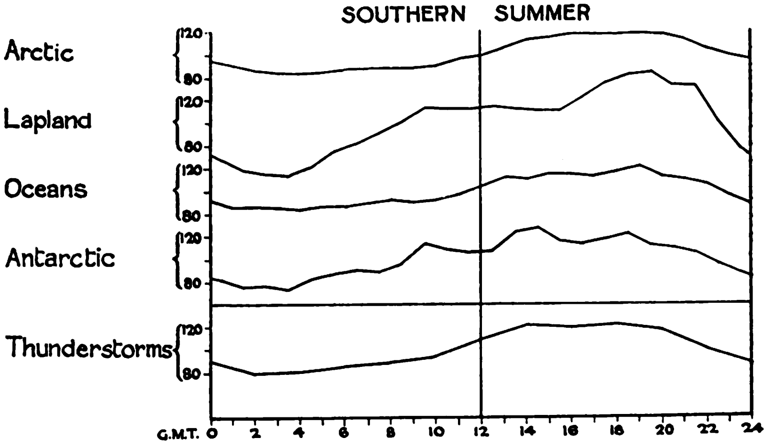

FIG. 2.—Diurnal Variation of Potential Gradient and of Thunderstorm Frequency in the Southern Summer. Percentages of mean values.

By 12h. G.M.T., when it is 2 p.m. in Central Africa, the gradient has risen considerably. The storms of West Africa and South America overlap and give a flat maximum to the potential gradient curve. The decrease to the minimum gradient as the area under the influence of the storms is reduced is fairly rapid.

The most noteworthy feature of the curves for the northern summer is the postponement of the drop of potential gradient at the end of the Greenwich day. This feature, which is common to the records for the oceans, for Lapland, and for the Antarctic, is explained by the lie of the Americas. North and Central America are west of South America and therefore the thunderstorms of the northern summer continue to a later hour by universal time than those of the southern summer. It must be admitted that our computed curve for the thunderstorms of the northern summer is not quite in agreement with the potential gradient curves. Possibly our statistics give too much weight to the thunderstorms of Europe and too little to those of Central America. We have only tried to count the storms; no attempt has been made to allow for the great variations in the electrical disturbance which is presumed to be the agent producing the flow of electricity to the fine weather regions.

4. SOME THEORETICAL CONSIDERATIONS.

It appears from our statistics that there is no appreciable delay between the generation of electricity in thunderstorms and the development of the corresponding potential gradient at remote parts of the globe. It is worth while to consider what delay is to be expected theoretically. Let us suppose that the electricity as it reaches the upper conducting layer is spread uniformly so that the rate of inflow of positive electricity over any part of the earth has the same value I. There is no accumulation of charge in the conducting layer, but the positive electricity flows steadily downwards from that layer. At any time the total positive charge in the column of air over unit area in a given region is equal to the negative charge on the ground there and each is equal to $F/4\pi$ where F is the potential gradient very close to the ground.[19] Since the total charge in a column of air is being diminished by the air-earth current and increased by the inflow from the conducting layer, we can write,

$$\frac{\partial}{\partial t}\left(\frac{F}{4\pi}\right) = I - \lambda F \quad . \quad . \quad . \quad . \qquad (1)$$

where λ is the effective conductivity for positive ions near the ground.

It follows that if λ is constant and if the variable part of I is equal to $J \sin nt$, then the variable part of F is equal to

$$\frac{J}{[\lambda^2 + (n/4\pi)^2]^{\frac{1}{2}}} \sin n\,(t - T)$$

where T is determined by the equation,

$$\tan nT = \frac{n}{4\pi\lambda}$$

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[19] The theory as stated in this simple form assumes that the ground is perfectly flat and uniform.

Now λ is of the order 10^{-4} in C.G.S. units and for oscillations with a period of 24 hours $n=2\pi/86400$, so that the time T, which represents the lag between the maximum of the inflow I and the maximum of the potential gradient, should be comparable with twelve minutes.

For our purpose such a short interval may be neglected and the agreement shown by the observations is explained. The importance of the condition that λ is constant will be noted. In parts of the world in which the effective conductivity varies considerably in the course of a day the changes in the potential gradient F will be governed partly by the changes in λ and partly by the changes in I.

In writing down the equation (1) we assume that the whole of the inflow of the electricity into a vertical column of the atmosphere occurs at the top. This assumption cannot be justified by *a priori* arguments, for we know that there are charges carried horizontally by the wind and it is not to be supposed that at most places the wind effect will cancel out. The evidence from diurnal variation appears to indicate that in the polar regions and over the oceans it does in the long run.

It is generally assumed that the transport of electricity through the atmosphere is entirely by ionic conduction. The part played by the turbulence of the atmosphere itself is ignored. The importance of turbulence can be realised by consideration of the passage of electricity through the clouds. One difficulty to be met in any theory of the maintenance of the earth's field is that the potential gradient is but little affected by the occurrence of ordinary clouds from which no rain is falling. It is known that a cloud is a very bad conductor of electricity and it has been suggested that it would be impossible for the air-earth current to find its way through a cloud. The low conductivity is no doubt due to the fact that any ions which may be present become attached to the droplets and lose their mobility. If a cloud is generated in such a position that it obstructs the air-earth current, the top of the cloud will catch positive descending ions and the bottom of the cloud will catch ascending negative ions. The result will be the production of a positive volume charge near the top of the cloud and a negative volume charge near the bottom. The effect of turbulence will be to bring positive electricity down and take negative electricity up. In the steady state the resultant vertical current of electricity will be the same inside the cloud as above and below it. We can not calculate the time required to establish the steady state, but our experience with fogs shows that the high gradient in the cloud must develop very quickly.

It appears that turbulence will also provide the explanation of the variations found by Wigand in the conduction currents at different heights in a clear atmosphere.[20] I hope to deal with this question in another paper.

5. THE ANNUAL VARIATION OF POTENTIAL GRADIENT AND OF THUNDERSTORMS.

The observations of potential gradient at sea and in polar regions agree in showing the highest mean values in the southern summer, the lowest in the northern summer.

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[20] A. Wigand. *Physik. Zs., Leipzig*, **22**, 1921, p. 624.

Thus we have for the oceans (Mauchly, *loc. cit.*, Table 79) the values :—

Nov.—Apr. 136 v/m.; May—Oct. 112 v/m.

for Karasjok (Lapland)

Oct.—Mar. 177 v/m.; Apr.—Sept. 101 v/m.

and for Cape Evans (Antarctic)

Oct.—Mar. 92 v/m.; Apr.—Sept. 79 v/m.

The question arises whether this phenomenon is to be explained by the incidence of thunderstorms.

According to Brooks's figures, which we have quoted above, the average numbers of days with thunder in the two halves of the year are :—

Oct.—Mar. 7.7; Apr.—Sept. 8.5

the averages being taken for the whole globe.

Our analysis gives for the land thunderstorms the following averages :—

Oct.—Mar. 14.6; Apr.—Sept. 15.6.

Thus days with thunder are more numerous in the northern summer. It is to be noted, however, that the storms of the southern summer are mainly in the tropics whilst those of the northern summer occur to a large extent in the temperate zone. No doubt the tropical storms produce much greater electrical disturbance, and it is probable that if we could make the appropriate allowance for this effect we should find that the total production of electrical energy was greater in the southern summer. This is only a suggestion for further research and for the present we must say that the higher potential gradient in the southern summer is not explained.

6. APPLICATION TO THE THEORY OF THUNDERSTORMS.

The general result of our investigation is that the Wilson theory is strongly supported by the close similarity between the observed changes in potential gradient and the changes required to keep time with the generation of electricity in thunderstorms. The evidence requires the net flow of electricity in a storm to be upwards. No satisfactory theory which will account for such a flow has been demonstrated and indeed Simpson's theory, which accounts for so many of the observed phenomena of storms, suggests that there should be a net flow of positive electricity downwards. The problem is being attacked, however, from many sides and it may be hoped that consistent explanations of all the principal phenomena of atmospheric electricity will be available in the near future.

DISCUSSION.

Sir **RICHARD GREGORY**: We are fortunate that Dr. Whipple has been able to give us such a clear digest of the details of his interesting paper. The effect of thunderstorms on the electrical condition of the atmosphere must be considerable, and such an investigation of their distribution and frequency in relation to variations of the potential gradient as is given in this paper provides a valuable contribution to a difficult problem. As bearing upon the direction of flow of electricity during thunderstorms, a short time ago Prof. C. V. Boys communicated to *Nature* a description of photographs taken by him which showed a lightning flash starting from the ground and almost immediately afterwards in the cloud, the flash travelling from both points and meeting in the middle. I should like to ask whether observations of atmospherics in connection with wireless have been considered by Dr. Whipple, as their frequency and distribution would seem to have a bearing upon the subject of his paper. As Dr. Simpson is a leading authority upon atmospheric electricity may I invite him to open the discussion of the paper.

Dr. G. C. SIMPSON said that the problem of the maintenance of the earth's negative charge is of such fundamental importance that every attempt to solve it is to be welcomed and should be carefully studied. Although he did not think that Dr. Whipple's paper provided the solution of this problem, it was a suggestion which needed to be considered and discussed thoroughly. The whole of the argument in Dr. Whipple's paper depended on the similarity between the curve which he constructed for thunderstorm activity and the curve for potential gradient in undisturbed parts of the world, for example, over the sea and polar regions. This similarity consists of only two features: (a) they are both mainly single 24-hour oscillations, and (b) there is a rough agreement in phase. The first means very little as most curves have a single wave and in any case the form of this curve is due almost entirely to the distribution of land and sea and has little to do with the distribution of thunderstorms. The chief point is the agreement in phase between the two curves. This is good but not perfect. The chances against the curves having this agreement are not great and alone it does not mean much. It would, however, be valuable support if there were evidence of a physical nature which required confirmation. In my opinion, however, there is no physical support to Wilson's hypothesis. I have over and over again discussed this point and have shown that all the evidence which Wilson adduces from what he calls clouds of positive polarity can be interpreted just as well by my theory in which the cloud is not of pronounced positive polarity. Accepting, however, for the moment that the clouds of thunderstorms have positive polarity so that the electromotive force of a thunderstorm is in the direction required for Wilson's theory, I see a number of objections, three of which only can be discussed now. In the first place I have made a simple calculation of the electrical field for a thunderstorm which has 100 coulombs of positive electricity at a height of seven kilometres above the surface, and I find that at 20 kilometres above the surface the potential gradient would only be 1,400 volts per metre and at 40 kilometres 140 volts per metre. With such electrical fields the conductivity of the atmosphere in this region is about 100 times too small to allow of the current necessary according to Wilson's theory. In the second place I do not agree with Dr. Whipple that there is sufficient turbulence in a layer of clouds to explain the continuance of the electrical field underneath a uniform layer of cloud. There are often periods when the sky is covered with low cloud (true stratus cloud) without any diminution of electrical field near the ground. This would be quite impossible if the Heaviside layer were the source of the charge which gives rise to the potential gradient. My third objection is that the Heaviside layer varies very greatly during the course of the day, being very largely affected by solar radiation. There are immense changes in the Heaviside layer both as regards height and intensity of ionisation at sunrise and sunset. These must give a strong term in local time in any phenomenon depending on the Heaviside layer. In my opinion this variation in local time would completely mask the variation in universal time due to thunderstorms.

Mr. R. A. WATSON WATT thought that Dr. Simpson's remarks did less than justice to the quantitative evidence supporting Wilson's views. While it was true that there was no completely determinate and unambiguous measurement of thundercloud polarity, yet numerous measurements made at widely differing distances from the discharge channel were available. Doubtless these could be fitted in with the Simpson mechanism, but interpretation in the Wilson sense is much more direct. In particular, measurements made by radiotelegraphic methods at 100, 300, and 600km. from the discharge channel agreed very closely with Wilson's determinations at short distances. It would be singularly bad luck if the simplicity indicated by this consistency could not be matched by an equal simplicity in the interpretation of the arrangement of charges.

On the general bearing of radiotelegraphic evidence on the subject matter of the paper, the measurements on atmospherics, if interpreted simply as thunderstorm data, would support the picture of thunderstorm activity drawn by the author. The predominant source of atmospherics at any given time lies over a land area where it is summer afternoon, and the number of atmospherics received supports Dr. Brooks' estimate of 100 lightning flashes per second. The number of individual atmospherics received at a tropical or sub-tropical station at night averages about 300 per second.

It may be noted that Prof. Appleton drew attention some years ago to the bearing of observations on distribution of thunderstorms and direction of arrival of atmospherics on Wilson's theory of the maintenance of the earth's charge. (*Proc. Physic. Soc.*, **37**, 1925, p. 49d). Reference to this paper gives an opportunity of correcting a misunderstanding. On the page already referred to Prof. Appleton refers to "Mr. Watson Watt's conclusion that only a quarter of the atmospherics are due to thunderstorms." No such conclusion had ever been drawn by Watson Watt, nor is there yet sufficient evidence for the drawing of a conclusion.

The difficulty, to which Dr. Simpson has called attention, in reconciling the absence of a local time term from the potential gradient curves with the known diurnal variation in height of the effective lower boundary of the upper conducting layers, may perhaps be sufficiently met by recognition of the fact that this diurnal variation of a somewhat arbitrarily defined boundary probably represents a negligibly small variation in total conductivity as compared with the very high conductivity in the regions well above the boundary.

Lieut.-Col. E. GOLD said that he understood that recent wireless investigations indicated the existence of at least three conducting layers, at heights of about 40 km., 100 km. and above 200 km. (These layers were not perfect conductors, but much better conductors than the lower atmosphere). The existence of three layers would naturally modify the electric field above the thunderstorm.

Mr. BONACINA thought that it was a pity that Dr. Whipple had not made full use of the data suited to his argument inasmuch as it appeared to be a fact of observation that the thermal lapse rate out at sea, together with the frequency of cumulus clouds and thunderstorms, was at a maximum in the early hours of the morning or about 12 hours distant from the land afternoon maximum in these elements. In relation to Dr. Whipple's comment upon the possibly greater intensity of electrical energy south of the equator, he wished to draw Dr. Whipple's attention to the probability that the summer thunder and hail storms of the Union of South Africa were the most violent in the world. In a written note Mr. Bonacina further added: This attempt to link up the quiet electricity of the atmosphere with the spectacular electricity of thunderstorms is likely to give a big impetus to the whole study of atmospheric electricity about which much remains to be learned. It is quite likely, for instance, that atmospheric electricity is a more significant climatic element in affecting our sensations than we are wont to suspect, and may have something to do with those subtle changes in the quality of the atmosphere from one day to another that seem difficult to attribute entirely to temperature, humidity, and wind.

Dr. WHIPPLE's reply*: I think that Dr. Simpson hardly does justice to the agreement between the curves showing the diurnal variation of potential gradient and of thunderstorm activity. The curves are not mere sine curves. They show the peculiarity of a slow rise and a comparatively rapid fall. The agreement is best in the case of the potential gradient curve depending on the largest number of observations, that for the Arctic Ocean in the southern summer. The agreement in phase within an hour or so could hardly be accidental. The odds against such consistency in unconnected phenomena are about 11 to 1. I agree with Dr. Simpson that similar results would have been obtained if some other phenomenon depending on the distribution of land and water had been considered. The diurnal variation in cloudiness or rainfall would have been shown by curves somewhat similar to those I have given for thunderstorms, but it is doubtful whether the amplitude of the variation would have been so large in comparison with the mean value. As to the general question whether during thunderstorms there is on balance a current of positive electricity from ground to atmosphere I should quote the experiments of Schonland in South Africa and Wormell in England. Those experiments favour Wilson's view that the principal way in which electricity is transferred in storms is by the discharge of positive electricity from pointed objects. It must be admitted, however, that the proportion of negative gradients to positive was higher in the thunderstorms observed by Schonland and by Wormell than in storms recorded by other observers, and that there is a danger in generalising from such limited experience. Further observations on similar lines are urgently required.

Dr. Simpson's calculation of the potential gradient in the upper air over a thundercloud was made on the supposition that the problem was one of simple electrostatics. I believe, however, that the fact that the atmosphere is a conductor should be taken into account in such calculations. The effective ohmic resistance between seven kilometres and the Heaviside layer is probably much less than the resistance between seven kilometres and the ground. The computation of the distribution of potential under such circumstances presents considerable difficulties. The difficulty of accounting for the passage of the air-earth current through clouds has to be met by any theory of the maintenance of the earth's fine weather charge. Whether turbulence is the main factor in the effective conductivity of the cloud could not be decided without special research. That no cloud is completely stagnant must I think be admitted. Radiation fog is cooled above and warmed below and there is evidence for convection through it. There are probably convectional movements through stratus cloud as well. Has not Brunt shown that the chequered pattern of alto-stratus is produced by the interplay of convection and radiation? The conductivity of the air is mainly due to the small ions. In the ordinary air the life of a small ion is about a minute. In the cloud the life may be reduced to a few seconds, but if the potential gradient is strong enough the ions will move quickly and this movement will constitute a vertical current of electricity. It may be that under certain circumstances this is the principal component of the current through the cloud. The variations in the height and conductivity of the Heaviside layer or layers in the course of the day were referred to several times in the discussion. It appears, however, that these variations would have little influence on the air-earth current. For the purpose in view the Heaviside layer at its worst can be regarded as a perfect conductor.

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* Partly communicated.

The President and Mr. Watson Watt referred to the diurnal variation in the frequency and intensity of atmospherics. The census of atmospherics has not been very thorough hitherto. By the installation of recording apparatus such as that of Fujiwhara at stations well distributed over the globe the daily changes in the centres of activity of thunderstorms could be followed. Incidentally the question whether storms occur over the oceans by night rather than by day would be settled. In my paper I have been unable to allow for the difference in intensity of the storms in various parts of the world. In statistics based on records of atmospherics such an allowance would be made automatically. I hope that such records will be available before long.

Sir RICHARD GREGORY: We have to thank Dr. Whipple for bringing before us a subject which has given rise to such a lively and stimulating discussion this evening. Colonel Gold has referred to three separate ionising layers in the atmosphere at different heights. In this connection it may be worth mention that Prof. Störmer, of Oslo, has recently shown the existence of remarkable radio echoes from three to fifteen seconds after the principal signal is received, and these seem to be produced by electric waves which have penetrated the Heaviside layer and been reflected by another boundary far out into space.

The Liverpool Observatory and Tidal Institute

On January 1, 1929, the Liverpool Observatory at Bidston, near Birkenhead, and the Tidal Institute of the University of Liverpool, amalgamated to form one institution under the above title.

Liverpool Observatory was founded in 1845 for the following purposes—the communication of time to the port, the testing and rating of chronometers and the taking of astronomical and meteorological observations. It was maintained by the Mersey Docks and Harbour Board and was situated on the Waterloo Dock Pierhead. In 1867 the reconstruction of the Waterloo Dock rendered it necessary to remove the

Observatory and it was transferred to Bidston Hill, which site it has occupied ever since. As the development of wireless messages has enabled the time to be distributed all over the British Isles from Greenwich Observatory, the importance of local observatories for time service has decreased; on the other hand the importance of meteorological observations has increased; hence the meteorological observations have lately become the most important part of the work of the Observatory, although the testing and rating of chronometers has been continued.

The Tidal Institute was founded by the University in 1919, and it is now recognised as the centre of tidal information for the British Isles.

The new institution is to be governed by a Joint Committee of the Mersey Docks and Harbour Board and of the Liverpool University. Professor J. Proudman, F.R.S., is the Director and Dr. A. T. Doodson is Associate Director.

Simms Gold Medal of the Royal Aeronautical Society

Captain F. Entwistle, B.Sc., F.R.Met.Soc., Superintendent of Aviation Services, Meteorological Office, has been awarded the Simms Gold Medal of the Royal Aeronautical Society. The Simms medal is given for the best paper on any subject allied to aeronautics; it was awarded to Captain Entwistle for his paper on " Fog " read before the Society on December 8, 1927. The medal was presented at a dinner held on December 17, 1928, round the original Wright aeroplane in the Science Museum, to commemorate the twenty-fifth anniversary of the first controlled flight in a power-driven aeroplane at Kitty Hawke, North Carolina, on December 17, 1903.

Prize for Meteorological Essay offered by M. Patxot i Jubert

Since 1922 M. Patxot i Jubert has offered yearly prizes for the best essays giving the results of original work in either science or mathematics. The subject for the competition in 1926 was the meteorology of the western Mediterranean with especial reference to the coast of Catalonia. We are now informed that this prize was not awarded; but as somebody is working on the subject the competition is to be repeated. Manuscripts must be sent in by December 31, 1929; they may be submitted in English, the Latin languages or in Catalonian. The subject should be treated from a dynamical standpoint.

Further information may be obtained from M. Patxot at Rue de la Cucurulla 1 and 3, Barcelona.

ATMOSPHERIC OSCILLATIONS SHOWN BY THE MICROBAROGRAPH.

By N. K. JOHNSON, M.Sc., A.R.C.Sc.

[Manuscript received in revised form Sept. 28, 1928—Read Nov. 21st.]

1. INTRODUCTORY.

Since the microbarograph was first described[1] little attention appears to have been paid to the records which this instrument gives. At the British Association Meeting in 1908 a discussion on the theory of wave motion was held, but as far as short period oscillations of the atmosphere are concerned, little was done beyond directing attention to the fact that such oscillations were occasionally recorded.

An important step forward was made by Goldie,[2] who showed that oscillations of the periods commonly observed are explicable as the result of wave motion at the interface of two air currents possessing different densities and motions.

The present paper, whilst not claiming to be in any way final, puts forward a few facts which have emerged from a preliminary analysis of the microbarograms from certain stations. Incidentally, the theory of the instrument is also discussed.

2. ANALYSIS OF SOME MICROBAROGRAMS.

Through the courtesy of the Director of the Meteorological Office an examination was made of the microbarograms obtained at Calshot, Croydon, Farnborough and Sealand, and particulars were recorded of all genuine instances of periodic oscillation. The numbers of such occasions which were found are shown below:—

TABLE I.

Station.	Years.	No. of occurrences of periodic oscillations.
Calshot .	1920-24	164
Croydon .	1920-24	1120
Farnborongh	1916-24	267
Sealand .	1922-24	321

The duration of the oscillations varied from 15 minutes to about eight hours, although the great majority lasted for about one or two hours.

The first thing that has been done is to plot the frequency of occurrence of oscillations of various periods. The result for the four stations is shown in Fig. 1.

In the case of Calshot there is a well-defined maximum frequency for a period of 10 minutes. There are also secondary maxima at 20, 30 and 40 minutes.

The Farnborough records give a somewhat different result with two nearly equal maxima at 11 minutes and 15 minutes. These two maxima are not very distinct, and taking into account the number of observations, the graph might be interpreted as showing a single maximum at 13 minutes.

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[1] *Q.J.R. Meteor. Soc.*, **31**, 1905, p. 39.
[2] *Q.J.R. Meteor. Soc.*, **51**, 1925, p. 239.

The Sealand records indicate a maximum frequency for a period of 17 minutes. The curve is not very regular, but even if we smooth the observations by taking means of three points at a time, the maximum is only shifted to 16 minutes. That this is a genuine maximum is supported by the occurrence of the "harmonic" at about 33 minutes.

The Croydon curve, based upon over 1,100 observations, gives a well-defined maximum at about 10 minutes, with possibly others at 20, 30, 35, 40 and 50 minutes. If we smooth the readings as before, we find the principal maximum corresponds to a period of 10½ minutes.

3. THEORY OF THE MICROBAROGRAPH.

Before proceeding further it is necessary to inquire to what extent the above results may be influenced by the peculiarities of the instrument from which the records were obtained.

a. In the first place the numbers of occurrence of oscillations given in the previous section differ considerably from one observatory to another. This difference is to be attributed to a number of factors. Foremost, probably, comes the fact that the records were analysed by the staff at each station. If the examination of all the charts had been carried out by one person, there is little doubt that the large difference in the numbers of oscillations would have been appreciably reduced. Differences in adjustment may also account for variations between two instruments. Friction in the pivots or on the float stem are both potential sources of difference. Again, in some instances, force of circumstances necessitates the instrument being placed in a situation such that fine detail of the trace is masked. Differences in the size of the leak in the various instruments may also account for some of the difference in apparent sensitivity. It must be noted, however, that appreciable differences in the leak would have a marked effect upon the frequency distributions. The similarity of the frequency distributions shown in Fig. 1 suggests that the effect due to differences in leak must be small.

b. In the second place we may notice that oscillations with a period of two minutes (or even less) are extremely obvious and very easily detected in the records of any properly adjusted microbarograph. The small number of oscillations of short period (say less than seven minutes) shown in Fig. 1 cannot therefore be attributed to difficulty of detection.

c. Thirdly, it is important to observe that the microbarograph has no natural period of oscillation which can be measured in minutes. This is, indeed, obvious from the construction of the apparatus; but if any proof is needed it is to be found by applying a slight reduction of pressure to the inside of the instrument. The pen will be observed subsequently to trace out an excellent decay curve, showing that the instrument is almost ideally dead-beat.

d. We now have to examine what part the leak may play in affecting the records given by the instrument. The object of the leak is, of course, to quench out pressure variations which occur slowly, but hitherto no attempt appears to have been made to ascertain quantitatively to what extent this effect occurs.

Suppose

P = external pressure.
p = internal pressure.
P_0 = initial pressure (both inside and outside).

Now from the Addendum to the paper containing the original description of the instrument[3] it will be seen that if a small change ΔP occurs in the external pressure, then the float would move by an amount equal to $\frac{1}{2} . \Delta P$ *if there were no leak.* The pen only gives a magnified record of the movement of the float, so for our present purpose we may regard the movement of the float as being equivalent to the trace.

Thus, if the external pressure varied in a manner given by

$$P = P_0 + 2A \sin\frac{2\pi t}{T} \quad . \quad . \quad . \quad . \quad (1)$$

and if there were no leak, the float movement would be given by

$$A \sin\frac{2\pi t}{T}$$

Owing to the leak, however, this displacement $A \sin 2\pi t/T$ will be diminished in the following way:—Suppose we obtain a decay curve in the manner referred to above, and suppose we find from it that the displacement D of the float (or pen) decreases according to the law

$$D = D_0 e^{-\alpha t} \quad . \quad . \quad . \quad . \quad (2)$$

D_0 being the initial displacement, t time and α a coefficient defining the size of the leak. Then

$$\frac{dD}{dt} = -\alpha D \quad . \quad . \quad . \quad . \quad (3)$$

It is a property of the instrument that the displacement of the float is always proportional to the instantaneous difference between the internal and external pressures.

Hence, if the external pressure is varying in the manner given by equation (1), the total resultant rate of change of displacement of the float will be given by

$$\frac{dD}{dt} = \frac{1}{2}\frac{dP}{dt} - \alpha D \quad . \quad . \quad . \quad . \quad (4)$$

or

$$\alpha D + \frac{dD}{dt} = \frac{2\pi}{T} A \cos\frac{2\pi t}{T} \quad . \quad . \quad . \quad . \quad (5)$$

The integration of this equation, combined with the condition that $D = 0$ at $t = 0$, yields

$$D = \frac{A}{1 + \frac{\alpha^2 T^2}{4\pi^2}}\left\{\sin\frac{2\pi t}{T} + \frac{\alpha T}{2\pi}\left(\cos\frac{2\pi t}{T} - e^{-\alpha t}\right)\right\} \quad . \quad (6)$$

For large values of t the exponential term becomes negligible, and the steady state is then given by

$$D = \frac{A}{\sqrt{1 + \frac{\alpha^2 T^2}{4\pi^2}}} \cdot \sin\left(\frac{2\pi t}{T} + B\right) \quad . \quad . \quad . \quad (7)$$

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[3] *loc. cit.*

where

$$\tan B = \frac{aT}{2\pi}. \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

We thus find that the amplitude A which would be recorded if there were no leak is reduced to

$$\frac{A}{\sqrt{1+\frac{a^2T^2}{4\pi^2}}}$$

and the phase of the recorded oscillation is advanced by the amount B.

The following table shows the value of the quantity

$$\frac{1}{\sqrt{1+\frac{a^2T^2}{4\pi^2}}}$$

and B for various values of aT.

TABLE II.

aT	$\frac{1}{\sqrt{1+\frac{a^2T^2}{4\pi^2}}}$	B (degrees).
$\frac{1}{3}$	0.998	3
1	0.988	9
3	0.903	25
10	0.532	58
30	0.205	78
100	0.063	86

We may here state that the decay experiments mentioned above have been carried out and values of a determined. It should be noted that a is the reciprocal of the time taken for the displacement in the decay experiment to fall to one eth of its initial value D_0.

The glass capillary tubes normally supplied for use in microbarographs were found to give values of $1/a$ of about one hour. In their original paper Sir Napier Shaw and Mr. Dines also show a decay curve for which the value of $1/a$ is about the same. If, then, we consider an instrument for which $1/a$ is one hour, aT will equal unity for an oscillation of which the period is also one hour. From the above table it is seen that such an oscillation is recorded at almost the same amplitude as if there were no leak. The reduction is even less in the case of oscillations of shorter period.

Similarly an oscillation of period three hours ($aT=3$) is reduced about 10 per cent., whilst one of 24 hours ($aT=24$) is reduced to approximately one quarter of the "no-leak" amplitude. The diurnal temperature, and therefore pressure, variation of the air inside the instrument corresponds to this value of aT.

In the case of a leak for which $1/a$ is less than one hour, the recorded amplitudes of oscillations of the same periods will also be less. For example, if the leak is so large that $1/a=5$ minutes only, oscillations of period equal to one hour are recorded at half the "no-leak" amplitude.

The damping effect of the leak as revealed by the foregoing analysis is, it is believed, less than is frequently supposed.

For our immediate purpose the fact which we have to observe is that, with a normal leak, oscillations with periods up to an hour are recorded by the microbarograph with no appreciable reduction in amplitude. Even if the leak were so large that the decay period ($1/a$) were equal to only one minute, oscillations of 40 minutes period would still be recorded with 0.3 times the amplitude of those of 10 minutes period. The actual decrease of frequencies shown in Fig. 1 is considerably more than this. It is, in fact, more rapid

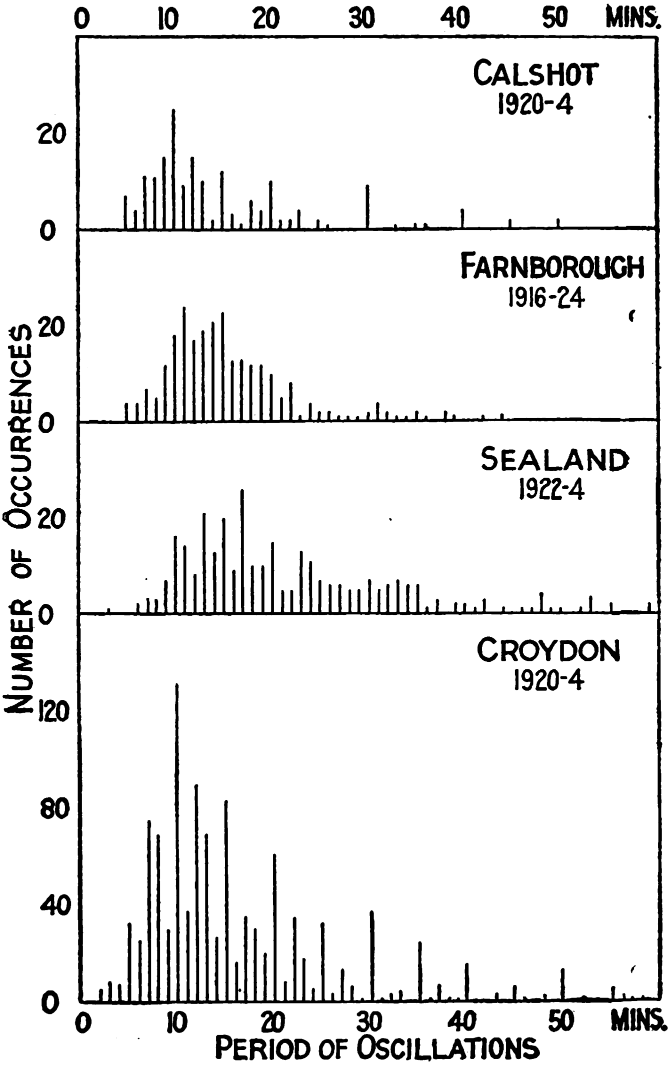

FIG. 1.

than can be accounted for by any possible value of $1/a$. The above argument involves the assumption that a reduction in the recorded amplitude of an oscillation causes an equal reduction in the chance of its being detected. In most cases oscillations are very well defined and nowhere near the limit of detectability, so that the probability of detection is reduced considerably less than is assumed above.

It will be seen, therefore, that the decrease in the frequency of occurrence of oscillations as we travel towards the right in Fig. 1 cannot be attributed to the damping out of long period oscillations by the leak.

We have already considered the decrease in frequency of oscillations with periods from about ten minutes downwards, and we are thus left with the conclusion that the frequency distributions shown in Fig. 1 are sensibly correct and free from any large errors due to instrumental causes.

4. Discussion of the Periods.

The four frequency curves previously considered, particularly that for Croydon, bear strong resemblance to resonance curves. The similarity is shown not only in the general shape of the curves but also in the occurrence of peaks corresponding to one or more harmonics of the fundamental period.

In a recent paper[4] it has been shown by Brunt that, provided the lapse rate is less than the adiabatic value, a small element of the atmosphere possesses a natural period of vertical oscillation given by

$$T=2\pi\sqrt{\frac{\theta}{g\left(\beta+\dfrac{d\theta}{dh}\right)}} \quad . \quad . \quad . \quad . \qquad (9)$$

in which θ is absolute temperature, g gravitational acceleration, β the adiabatic lapse rate and h height. (For adiabatic conditions $\beta=-d\theta/dh$.) Taking θ as 300 absolute we find the following periods corresponding to various temperature gradients.

Table III. is shown graphically by the curve of Fig. 2, which will be referred to again later.

TABLE III.

Period T.	Temperature Gradient. $\frac{d\theta}{dh}$		Period T.	Temperature Gradient. $\frac{d\theta}{dh}$	
Min.			Min.		
1	3.3β	Inversions.	7	-0.33β	Lapses.
2	7.4β		10	-0.66β	
3	2.7β		15	-0.85β	
4	1.1β		20	-0.92β	
5	0.34β		30	-0.96β	
5.8	0	Isothermal.	40	-0.98β	
			50	-1.00β	

If θ is taken as 280° absolute instead of 300° absolute the periods shown are altered by only about four per cent.

This relationship between temperature gradient and period of oscillation refers to a small element of the atmosphere and cannot,

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[4] *Q.J.R. Meteor. Soc.*, **53**, 1927, p. 30.

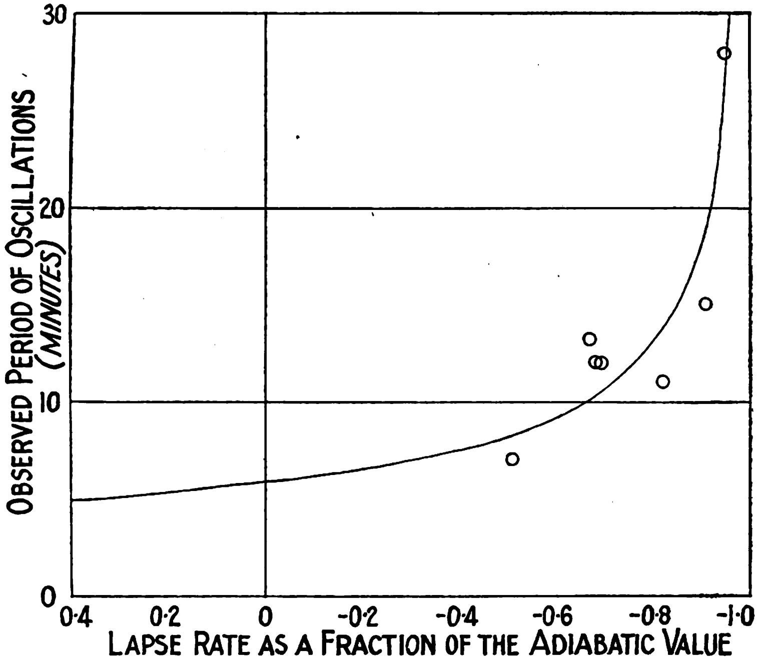

Fig. 2.—Comparison of observed lapse rates and periods with Brunt's equation.

without further investigation, be taken as applying to the atmosphere as a whole. A direct test has therefore been made by means of the Farnborough records to see whether this same relationship holds good for the oscillations of the atmosphere as shown by microbarograph traces. Mr. W. H. Bigg has kindly extracted from the Farnborough records details of the temperature structure as obtained by aeroplane ascents on all occasions on which periodic oscillations were shown on the Farnborough microbarograms. Only ten occasions have been found on which the oscillations were actually in progress while the upper air observations were being made. On three of these occasions the temperature gradient consisted of an inversion starting at ground level and eventually giving way to a lapse. These cases cannot be dealt with owing to the difficulty of assigning a " mean " value to the gradient.

The remaining seven cases are interesting from the fact that in every case a moderate lapse rate in the first few thousand feet is surmounted by an inversion. The heights at which these inversions occurred and also the mean lapse rates up to these heights are shown in the following table.

The occurrence of these inversions would seem to afford direct evidence of the existence of those surfaces of discontinuity at which Goldie[5] suggested that these oscillations might originate.

The fourth column of Table IV. shows the observed lapse rates expressed as fractions of the dry adiabatic value (5.5°F. per thousand feet). The last column gives the period of the oscillation

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[5] *loc. cit.*

TABLE IV.

Date	Height of base of inversion.	Mean gradient from ground to base of inversion.	Gradient expressed as fraction of adiabatic value.	Period of oscillation shown by microbarograph.
	ft.	°F./1,000ft.		mins.
20/3/24	2,000	5.25	0.95	28
24/6/20	1,000	5.0	0.91	15
17/2/21	4,000	3.7	0.67	13.3
30/7/21	4,000	3.75	0.68	12
27/5/22	4,000	3.75	0.68	12
9/5/24	5,000	4.5	0.82	11
17/10/24	6,000	2.8	0.51	7

recorded by the microbarograph simultaneously with the aeroplane ascent. The fourth and fifth columns are shown plotted against each other in Fig. 2. The continuous curve is the relationship given by Brunt's expression (equation 9). It will be seen that the data of Table IV. are a very fair fit to this curve. A larger number of observations would admittedly be desirable if they could be obtained, but it is submitted that the agreement shown in Fig. 2 is sufficiently good to justify the conclusion that Brunt's equation applies not only to oscillations of an element of the atmosphere, but also to those oscillations in the lower atmosphere which are recorded as periodic variations on microbarograms.

We have seen that the periods which have been found in microbarograms lie in the same region as the natural period of oscillation of the atmosphere. Indeed, it seems clear that we are here dealing with a case of true resonance. If these oscillations originate at a height of about a kilometre at the interface of two currents, it is evident that pressure variations of appreciable amplitude will be transmitted to ground level most frequently when the period of the wave motion agrees with the natural period of oscillation of the kilometre depth of atmosphere at that time. If the period of the wave motion differs considerably from the period of oscillation of the atmosphere at the time, then the original disturbance will not be recorded at the ground unless it is of exceptionally large amplitude.

Except at times of strong insolation, the most frequent value for the temperature gradient in the lowest kilometre is about two-thirds of the dry adiabatic value, corresponding to a natural period of oscillation of about 10 minutes. The principal maxima in the frequency curves for Calshot and Croydon are thus accounted for. Moreover, if the original wave motion possessed a period which was a multiple or harmonic of the period of oscillation of the atmosphere, resonance would again occur, and the microbarograph at the ground would again record comparatively large pressure variations. The secondary maxima or harmonics which show up in the frequency curves might thus correspond with temperature gradients corresponding to either the fundamental or the harmonic.

The Farnborough maximum at 15 mins. and the Sealand one at 17 mins. apparently indicate the prevalence of lapse rates somewhat in excess of two-thirds the adiabatic value. The reason for this is not obvious. An attempt to separate the Farnborough oscillations of 11 mins. from those of 15 mins. showed that the latter were associated with somewhat more frequent N. winds.

However, the majority of both classes occurred with winds between SW. and W. No attempt has been made to group the periods under headings of equatorial and polar air.

5. Times of Occurrence of Oscillation.

We have been considering the view that the periodic oscillations shown on microbarograms originate as wave motion at the interface of two air currents—probably at a height of about a kilometre—and that pressure variations of appreciable amplitude occur at the ground when the natural period of oscillation of the lower atmosphere agrees with that of the wave motion. Additional support to this view is given by a consideration of the times at which these oscillations are recorded. It is clear that a super-adiabatic lapse rate, such as occurs on a summer day, should largely inhibit these oscillations; firstly, because the convection would tend to destroy the interface of the two air currents, and secondly, because the lower atmosphere has now no natural period, and resonance consequently cannot occur.

The times of occurrence of microbaric oscillations at Farnborough have been examined and the result is given below.

TABLE V.

Months.	00.00-08.00.	08.00-16.00.	16.00-24.00 G.M.T.
Dec., Jan., Feb.	42	13	25
Mar., Apr., May	27	12	23
June, July, Aug.	39	5	21
Sept., Oct., Nov.	24	14	22
Yearly total as percentage	50%	16%	34%

The table shows the number of occasions on which oscillations have been recorded during the three eight-hour periods indicated, for the four quarters of the year. The small number occurring during the daytime, and especially in summer, is in agreement with what has been anticipated. It is seen also that oscillations are recorded more frequently between midnight and 08.00 than between 16.00 and midnight.

The Calshot observations have been treated in the same way and yield the same results. Middle day of summer again gives very few occasions, and the morning period again gives more than the evening.

Such oscillations as do occur on summer days are probably to be included in the category which we have been considering. Super-adiabatic lapse rates extending to a height of a kilometre do not occur on every summer day.

On the other hand, disturbances associated with thunderstorms are quite different and are usually very heavily damped.

In addition, there are certain quasi-periodic variations of pressure which occur on summer days and which appear to be connected with large scale convection.[6] These again are totally distinct from the genuine oscillations which have been discussed in the present paper.

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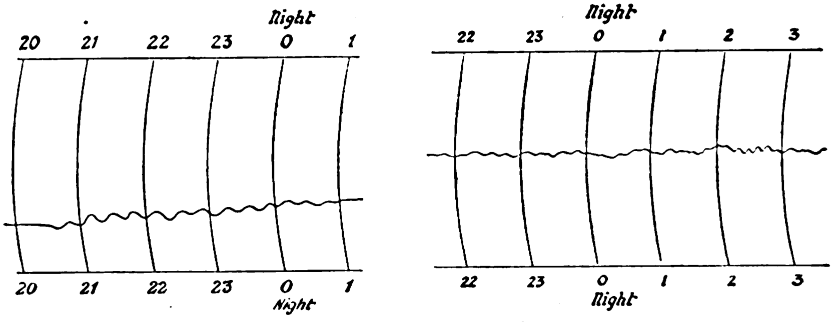
[6] See *Nature*, Feb. 21st, 1925, p. 263.

6. Change of Period.

On some occasions a sustained oscillation is shown on a microbarogram and after perhaps half-an-hour it changes its period. About twenty such cases have been found among the Sealand records. The change may consist of either an increase or a decrease in the period. In a few cases the period increased to double its initial value, but these instances are exceptional rather than the rule. Normally there seems to be no connection between the original and final periods.

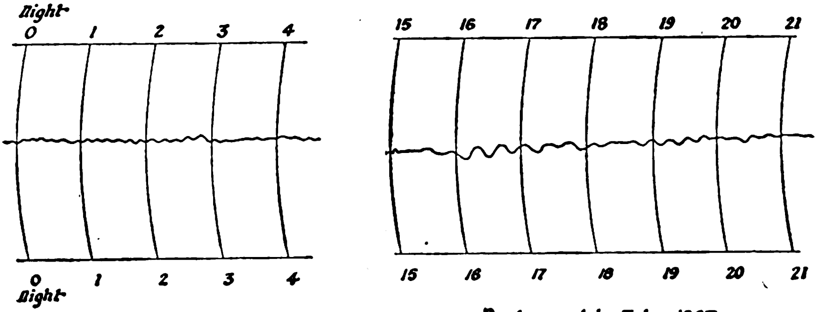
It would appear that such changes of period are probably due to changes of temperature in one of the air currents which produce the surface of discontinuity. If such a change occurred in the upper current it would alter the period of the wave motion, but not the natural period of oscillation of the mass of air beneath. Resonance might therefore occur at an overtone. On the other hand, a change of temperature in the lower current would change both the period of the wave motion at the interface and also probably the natural period of oscillation in the current itself. In such cases resonance might occur at a new period which would bear no relation to the previous period. If the new natural period of oscillation did not agree with the changed period of the wave motion, then the oscillations originally recorded at the ground would probably fade away.

Some typical microbarograms are shown in Fig. 3.



Sealand. 19th.Feb. 1926.

Porton. 31st. Oct. 1927.



Porton 30th.Mar.1927.

Porton 4th.Feb. 1927.

Fig. 3.—Examples of oscillations shown by Microbarographs.

DISCUSSION.

Sir RICHARD GREGORY: This is another paper particularly appropriate for presentation to a meeting of our Society and likely, I think, to lead to discussion by some Fellows present. I am not myself familiar with microbarographs or their records, but the oscillations explained by Captain Brunt remind me of the microseisms recorded on seismographs, and it seems possible that periodic oscillations in the atmosphere may have a response in pulsations of parts of the earth's crust. Perhaps Sir Gilbert Walker can enlighten us on this and other points raised by the paper.

Sir GILBERT WALKER said that in his view Captain Brunt was modest when he spoke of his period of oscillation as being that of a particle: it seemed likely that when larger masses, especially in the form of horizontal sheets, were involved, the period would not be widely different. Oscillations were also shown on barograph traces in India when a tropical cyclone was in the neighbourhood.

Dr. F. J. W. WHIPPLE said that he welcomed the paper because he thought that more use should be made of the beautiful records produced by the microbarograph. It would be of great interest to compare the waves recorded simultaneously at different stations, especially at a group of neighbouring stations such as Croydon, Kew and S. Kensington.

Lieut.-Col. E. GOLD said that he assumed that the waves arose through oscillation of the layer of air between the irregular earth's surface (a fixed boundary) and an inversion at some altitude which constituted a flexible constraining surface. Waves would always be produced at the inversion whether the temperature gradient in the layer of air were less than the adiabatic gradient or no. Waves ought therefore to occur in the daytime as well as at other times: whenever, in fact, there was an inversion with different winds above and below it. [Added Nov. 22nd: It is possible that there is much greater damping when the temperature gradient is adiabatic or super-adiabatic and that, in consequence, the wave motion remains too small to produce effects visible on the microbarograph record. In time, of course, a super-adiabatic gradient would dissipate an inversion: but inversions do exist with very high temperature gradients in the lower layers in the middle of a summer day.]

Dr. G. C. SIMPSON said that he was suspicious of the maxima which appeared at 10, 12, 15, 20 and 30 minutes in the results for Calshot and Croydon. If the observer had determined the average length of the waves by counting the number which occurred in an hour he would just get these values, for they corresponded respectively with 6, 5, 4, 3 and 2 waves per hour. If this should prove to be the case these maxima had no physical meaning and were not harmonics of a fundamental wave as suggested in the paper.

Mr. R. CORLESS stated that periodic variations of wind speed and direction had frequently been noticed on anemograms from Southport, Aberdeen and elsewhere, and that 20 minutes was a common value of the periodic time shown on such records. Sir Napier Shaw had discussed this "yawing" of the wind at Southport in a paper which was contributed to the Society many years ago.

He asked whether the wind records had been examined for any of the cases for which periodic pressure variations were shown.

Mr. D. BRUNT, in reply, said that no comparison of microbarograph oscillations and microseisms had been made, so far as he knew. [Added later: The microseisms usually discussed have much shorter periods, a few seconds only.] In reply to Dr. Whipple he said that no comparison of the oscillations at adjacent stations had been made, though it should be possible to compare the oscillations at South Kensington, Kew, Croydon and South Farnborough, on individual occasions. In reply to Mr. Corless Mr. Brunt stated that no comparison had been made with the wind records for the times when the microbarograph oscillations occurred. He was not able to say definitely in reply to Dr. Simpson how the periods of the oscillations had been estimated, though it should be easily possible to estimate these within about 1 minute, in view of the reasonably open scale of the microbarograph. [Added later, in writing: Colonel Gold raised a query as to whether convection during the afternoon might not affect merely a restricted layer near the ground, without breaking down any inversion which might exist at say 3,000 feet. On the views put forward in the paper, the convection should suffice to destroy the coincidence between the dynamical oscillation at the top of the inversion and the natural period of the lower layers, and so diminish the intensity of the oscillation observed at the ground. The observational data available are insufficient to decide precisely what happens in such cases. The method of derivation of the equation (9) quoted by Mr. Johnson does not pretend to give the mechanism by which the oscillations are produced. In deriving that equation no allowance was made for changes of pressure at the ground. Sir Gilbert Walker suggested in the course of the discussion that equation (9) probably still holds on theoretical grounds. I find it difficult to put the theoretical argument into a satisfactory form, and prefer at the moment to regard Mr. Johnson's Fig. 2 as justifying the use of my equation].

Mr. JOHNSON, in a written reply, said: "I would like to thank Mr. Brunt both for his kindness in presenting my paper and also for the interest which he took in the investigations described in it.

I have seen Mr. Brunt's replies to the questions raised and I am in complete agreement with them. The only point calling for further comment is that raised by Dr. Simpson. My attention has also been directed to the same point by Mr. Scrase, who, in co-operation with Dr. Whipple, has discussed this matter in a recent paper.[7] Since then I have communicated with the observers who analysed the Croydon and Calshot microbarograms. In both cases I am informed that the periods were not determined by counting the number of waves which occurred in an hour. The procedure consisted in measuring the time corresponding with an exact number of oscillations.

Sir RICHARD GREGORY: In offering our thanks to Mr. Johnson for his paper and to Captain Brunt for his account of it, I am sure the Fellows will agree with me that we have had two valuable contributions this evening and that the discussions upon them have been of decided interest.

March Lecture

The annual G. J. Symons Memorial Lecture will be delivered on March 20th, at 7 p.m., by Mr. R. A. Watson Watt, the subject being "Weather and Wireless." The lecture will be illustrated by lantern slides and also by wireless demonstrations.

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[7] On the frequency of microseisms of different periods at Eskdalemuir and at Kew. *Monthly Not. R.A.S. Geoph. Suppl.*, October, 1928.

ON THE MEAN MAXIMUM RAIN FALLING IN A TIME t.

By H. JAMESON, B.Sc., F.R.Met.Soc.

(Colombo Observatory, Ceylon.)

[Manuscript received April 23—Read Nov. 21st, 1928.]

In a paper now in course of publication,[1] I formulated a law, from studies of Ceylon rainfall, which may be expressed as follows:—

Compute the maximum value of the total rain falling on t consecutive days in any year. Let R represent the mean of a number of such values for different years, then, if this mean is taken over a sufficient number of years, we have

$$R = Qt^k$$

where Q and k are constants for any particular station and period of years, and t is a small number of days.

This formula holds at least as far as 10 days, for stations representative of all the different types of rain occurring in Ceylon, while in some cases I have shown it to hold for appreciably longer periods, in one case as long as 26 days.

The law can alternatively be expressed in terms of intensity. If I is the mean yearly maximum intensity in t days, we have a similar formula

$$I = Q't^{k-1}$$

It is of interest to investigate whether this law holds for values of t smaller than a day. We have very few pluviographs in Ceylon, and only for a small number of years have the records been reduced to hourly values. However, in our library I discovered three long series of published hourly values, for Batavia,[2] Hongkong[3] and New York.[4] From these I computed for each year the maximum rainfall in from 1 to 10 consecutive hours, and from 1 to 10 consecutive days. As the heaviest rains at Batavia come about the turn of the year, I took the twelve-month July to June as a better representative of the rainfall year there than the calendar year would be. August to July would have been still better, but for this purpose the difference cannot be appreciable. In the case of the New York publications, in each of the five years examined, the hourly values for one month, and in one year, the hourly values for two months were missing from our shelves. A few of the yearly maxima for hours may therefore be erroneous, but this should not appreciably affect the means.

All three sets of hourly and daily maxima, of course, refer to hours and days commencing at a definite minute and hour respectively. The mean maxima are given in Table I., and are plotted logarithmically, log(rainfall) against log(time), in Fig. 1.

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[1] Jameson, H., "The maximum total rainfall on consecutive days." *Colombo, Ceylon J. Sci.*, (Sec. E), **1**, pt. 2, 1928. See also *Nature, London*, **121**, 1928, p. 170.

[2] *Batavia, K. Mag. Met. Obs., Observations*, 1874-78 and 1889-1923.

[3] *Hongkong, R. Obs., Observations*, 1884-96, 1907-25.

[4] *New York Met. Obs., Reports*, 1889-92, 1894-1901, 1903-26.

TABLE I.—MAXIMUM VALUES OF RAINFALL FOR PERIODS OF 1 TO 10 HOURS AND 1 TO 10 DAYS AT BATAVIA (38 YEARS), HONGKONG (33 YEARS), NEW YORK (36 YEARS).

	t	1	2	3	4	5	6	7	8	9	10
Batavia (mm.)	hours	57.5	75.7	82.5	88.1	92.7	96.5	99.3	102.2	104.1	106.0
	days	109.2	136.3	163.9	181.0	197.0	210.0	225.2	237.6	257.6	269.8
Hongkong (in.)	hours	2.18	3.45	4.31	4.93	5.48	6.07	6.51	6.82	7.10	7.32
	days	8.27	11.67	13.23	14.00	14.80	15.50	16.20	16.70	17.17	17.78
New York (in.)	hours	1.10	1.52	1.77	1.95	2.13	2.31	2.43	2.55	2.67	2.77
	days	2.95	3.65	3.87	3.98	4.17	4.36	4.68	4.85	5.00	5.16

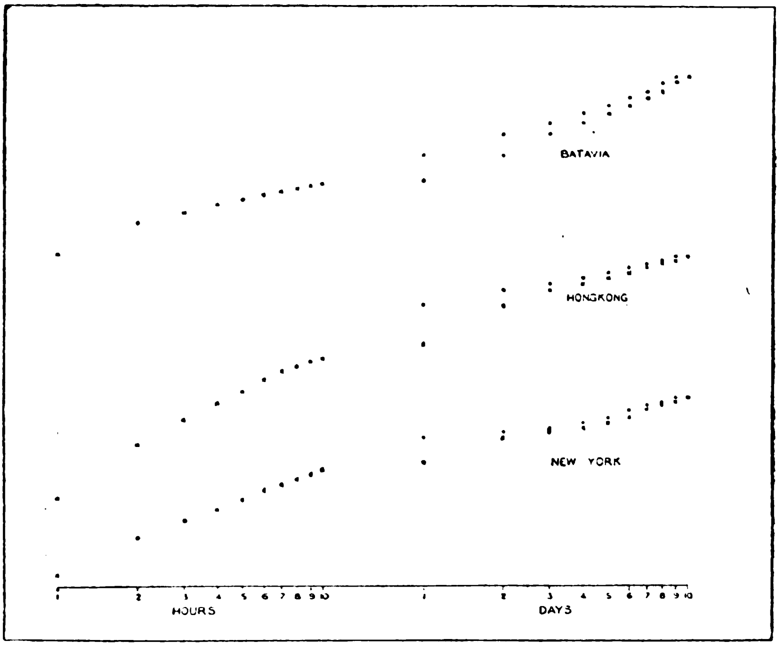

FIG. 1.

After I had completed the greater part of the computations for Batavia, I discovered in a paper by Dr. Figee,[5] a table giving the highest total fall each year, in from 1 to 24 consecutive hours, over the period 1866-1900. In this case the years are calendar years, and apparently these figures, too, refer to hours commencing at a definite minute. The table was due originally to Mr. A. P. Melchior, a civil engineer. The mean maxima from this table are given in Table II., and are plotted logarithmically in Fig. 2.

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[5] Figee, Dr. S., "On rainfall at the Batavia Observatory." *Batavia, K. Mag. Met. Obs., Observations*, 1900, App. II.

TABLE II.—MEAN MAXIMUM VALUES OF RAINFALL AT BATAVIA IN FROM 1 TO 24 CONSECUTIVE HOURS (1866-1900).

Hours.	1	2	3	4	5	6	7	8	9	10	11	12
mm.	53	74	85	91	96	100	101	104	106	108	109	110
Hours.	13	14	15	16	17	18	19	20	21	22	23	24
mm.	110	111	112	113	114	115	115	116	117	118	119	120

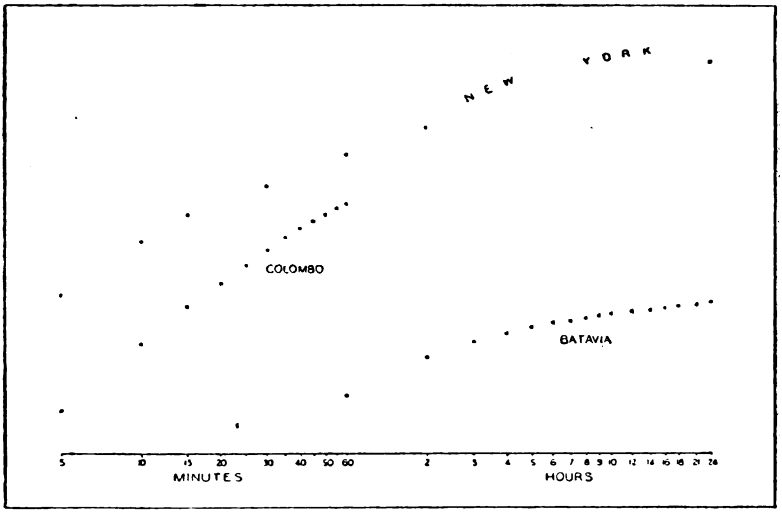

FIG. 2.

From data published in recent New York Meteorological Observatory reports, I extracted, for each year, from 1911-26 inclusive, the highest total fall in 5, 10, 15, 30 minutes, 1, 2, 24 hours. As the figures for 1 and 2 hours are higher than the corresponding figures in my own computations, the time intervals in this set of data are presumably not restricted to commence at a definite time. The mean maxima are given in Table III., and are plotted logarithmically in Fig. 2.

TABLE III.—HIGHEST TOTAL FALLS IN VARIOUS PERIODS AT NEW YORK (1911-1926).

Time.	5 min.	10 min.	15 min.	30 min.	1 hour.	2 hours.	24 hours.
Mean max. (in.)	0.40	0.64	0.80	1.03	1.36	1.72	3.08

From a memoir by Mr. Bamford[6] I deduced approximate values of the maximum rainfall at Colombo in 5, 10, 15, 20, . . . 60 minutes for each of the ten years 1904-13. The mean maxima are

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[6] Bamford, A. J., "On the intensity of rainfall experienced in Ceylon." *Mem. Colombo Obs.*, **1**, 1914.

TABLE IV.—HIGHEST TOTAL FALLS IN VARIOUS PERIODS AT COLOMBO (1904-1913).

Minutes.	5	10	15	20	25	30	35	40	45	50	55	60
Mean max. (in.)	0.46	0.83	1.14	1.40	1.64	1.87	2.10	2.26	2.41	2.56	2.69	2.81

given in Table IV., and are plotted logarithmically in Fig. 2. Although the period is so short, the figures give quite a smooth graph.

The "day" graph for Batavia (Fig. 1) shows a well-marked linear relation between 1 and 10 days, while that for Hongkong is quite linear from 2 to 10 days, the point for 1 day falling below the line. The corresponding graph for New York is very irregular, but the points from 4 to 10 days seem to indicate a linear relation.

The value of *k* at Batavia, 1-10 days, comes out as 0.40, that at Hongkong, 2-10 days, as 0.26, that at New York, 4-10 days, as 0.30. These numerical values seem to agree fairly well with those obtained from places in Ceylon. In this island, *k* is about 0.5 up-country, where the heaviest rain is mainly orographic, and diminishes as we move away from the influence of the hills, the lowest values I have so far found being about 0.3 at places where the heaviest rains are probably mainly depressional. In the temperate zones the weather usually consists of a succession of barometric highs and lows, the latter bringing the rain, so that the heaviest rains at New York should be more akin to the depressional rains of the tropics than to tropical monsoon rain. Hongkong is notoriously subject to typhoons, 214 having been registered in the China seas in 85 years,[7] and here again it is likely that nearly all the heaviest rains are depressional. The rainfall at Batavia seems to be monsoonal; according to Dr. Boerema,[8] along the north coast of west Java the rainfall is controlled entirely by the monsoons. The value of *k* at Batavia, 0.40, is distinctly lower than the values obtained for those hill stations of Ceylon, whose heaviest rains are due almost entirely to the orographic rains of one or the other monsoon, but agrees better with the figures for Colombo (0.45) and Batticaloa (0.43), both of which are low-country coast stations, subject to heavy monsoon rains. I was inclined to explain the lower values of *k* at these Ceylon coast stations as due to the relatively greater influence of depressional rain at that distance from the hills, but it is possible that coastal orographic rain has a lower exponent than that of the hill-country.

The graphs for periods of less than a day show that the same linear logarithmic formula no longer holds at these values of *t*. All three "hour" graphs in Fig. 1 have different mean slopes from the corresponding graphs for 1 to 10 days, while the Batavia and Hongkong graphs seem to be slightly curved. The New York and Colombo graphs in Fig. 2 are distinctly curved.

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[7] Doberck, W., "On the relative frequency of storms in various seas." *Hongkong, R. Obs., Observations*, 1884, App. E.

[8] Boerema, Dr. J., "Rainfall types in the Netherlands Indies." *Batavia, K. Mag. Met. Obs., Verh.*, **18**, 1926, p. 66.

I would suggest that the formula

$$R=Qt^k$$

holding for values of t of the order of a few days, is an expression of the statistical laws governing the distribution of separate rainstorms in time, and that for smaller values of t we are rather concerned with the physics of rain than with the statistics of rainstorms.

The "hour" graphs, if continued to 24 hours, should not be continuous with the "day" graphs, as the mean maximum for t days will usually be lower than that for $24t$ hours. The latter will, however, lie between the values for t and for $(t+1)$ days. I have plotted $\log R$ for $(t+1)$ days against $\log t$ as a dot, $\log R$ for t days, against $\log t$, being shown as a cross. The continuation of the "hour" graphs will lie between the "cross" and "dot" graphs, but probably nearer the former.

At Batavia the slope of the graph diminishes to a minimum before increasing again to the constant slope of the "day" graph. This diminution shows up quite well in the diagram in Fig. 2. At New York a similar effect is suggested at $t=4$ days. The Hongkong graph, however, suggests that the slope of the "hour" graph steadily diminishes till it reaches the constant slope of the "day" graph. For Batavia and New York, the suggestion is that after a spell of heavy rain, the rain-producing capacity of the atmosphere for a time becomes exhausted, and that this stage is reached, and passed, earlier in the case of the orographic rain of the tropical station than the depressional rain of the temperate zone station. This, too, would explain the irregularity in the earlier part of the "day" graph for New York.

Another point of interest is that the mean slopes of the "hour" graphs for the presumably depressional stations, new York and Hongkong, are both of about the same order of magnitude, and decidedly greater than that of the monsoon station, Batavia. As already mentioned, the converse is the case with "day" graphs, k being greater for monsoon than for depressional rain.

Further data from other places would perhaps throw more light on these interesting points.

There is a further point that should be of some practical interest to engineers. In Tables V.-VII. I have given, for Batavia, Hongkong and New York, the distribution of the figures for the maximum rain each year in 1, 2, 4, 7, 10 consecutive hours and for 1 day. These tables show that practically all the rainfall of the heaviest day's rain can usually be taken as falling within 10, or even within 7 hours, while a disproportionately large fraction of that amount falls within 1, 2 or 4 consecutive hours. Dr. Figee,[5] in the paper already referred to, points out that, in his "ideal" heavy shower, more than 50 per cent of the day's rain falls within two hours.

The maximum rainfall ever registered in a day at any place is a figure that is frequently required by engineers. It is probable that the assumption is made that this rainfall is distributed fairly evenly over the 24 hours, much more evenly than I have shown to be the case for the three stations discussed above. As these

THE DISTRIBUTION OF THE MAXIMUM RAINFALLS IN EACH YEAR IN VARIOUS PERIODS.

TABLE V.—BATAVIA.

Period.	Amount.							
	mm. 20-40	mm. 40-60	mm. 60-80	mm. 80-100	mm. 100-120	mm. 120-140	mm. 140-160	Over 160 mm.
1 hour	3	19	15	1	0	0	0	0
2 ,,	0	8	19	9	1	0	1	0
4 ,,	0	4	15	9	5	1	4	0
7 ,,	0	3	12	11	5	2	2	171, 180, 221
10 ,,	0	2	10	11	7	2	2	165, 187, 194, 270
1 day	0	2	8	9	9	5	1	170, 172, 241, 249

TABLE VI.—HONGKONG.

Period.	Amount.												
	in. 1-2	in. 2-3	in. 3-4	in. 4-5	in. 5-6	in. 6-7	in. 7-8	in. 8-9	in. 9-10	in. 10-11	in. 11-12	in. 12-13	Over 13 in.
1 hour	17	11	5	0	0	0	0	0	0	0	0	0	0
2 ,,	2	13	10	4	1	3	0	0	0	0	0	0	0
4 ,,	0	7	8	7	5	1	1	1	1	0	2	0	0
7 ,,	0	1	5	7	8	3	3	1	1	1	1	0	16.1, 18.8
10 ,,	0	0	3	4	8	5	4	1	3	1	1	1	16.9, 20.6
1 day	0	0	1	4	6	5	2	5	1	4	1	1	13.5, 20.5, 21.0

TABLE VII.—NEW YORK.

Period.	Amount.							
	in. ½-1	in. 1-1½	in. 1½-2	in. 2-2½	in. 2½-3	in. 3-3½	in. 3½-4	Over 4in.
1 hour	18	13	4	0	0	1	0	0
2 ,,	4	21	6	2	2	0	1	0
4 ,,	0	6	19	6	3	1	0	4.2
7 ,,	0	1	9	13	8	3	0	4.6, 4.9
10 ,,	0	0	6	10	10	4	4	4.9, 6.4
1 day	0	0	3	12	9	4	4	4.3, 4.8, 5.0, 7.3

stations differ widely from one another, both geographically and meteorologically, it is likely that an appreciable portion of such data, maximum daily rainfalls, are distinctly misleading. A knowledge of the relation between the maximum rain in a day and the maximum rain in *t* hours, at places where pluviographs are installed, should be of considerable value for the interpretation of the figures, where daily rainfall readings only are available.

The results given in this paper are incomplete and somewhat inconclusive. Neither the data nor the time were available for a more complete investigation, which may perhaps be carried out by someone better situated in these respects.

THE DINES FLOAT BAROGRAPH

By L. H. G. DINES, M.A.

[Received September 22—Read December 19, 1928.]

PART I.—DESCRIPTION

INTRODUCTORY

The instrument described in this paper was originally designed by the late W. H. Dines, F.R.S., about 20 years ago, but no complete description of it has been published. Examples of the instrument have been in use at the Meteorological Office and at certain observatories for a number of years, and have proved satisfactory.

The instrument consists essentially of a syphon barometer of special form, with upper and lower reservoirs of equal diameter. The movements of the mercury in the lower reservoir, due to changes of atmospheric pressure, are communicated by means of a float to the recording pen, through the intermediary of a pair of concentric pulley wheels, whereby an overall magnification of about two to one is obtained. The pre-eminent features are a very stiff control of the pen, an almost entire absence of friction in the working parts and an exceedingly small error attributable to capillarity. A faithful representation of the actual changes in atmospheric pressure is made, and, as a very fine pen is employed, minor variations of an amplitude as small as one or two tenths of a millibar can be studied as well as ordinary movements. The record will bear magnification and to a certain extent is equivalent to a microbarogram. The instrument entails very little trouble to keep in continuous operation. An illustration of the complete instrument is given in Fig. 1.

Any form of mercury barometer is subject to a large temperature effect and some form of compensation is essential. The details of that employed in the Dines float barograph are described below, and, as will appear in the second part of the paper, the correction is not quite perfect over the whole ranges of pressure and temperature experienced. The magnitude of the residual error is indicated and is seen to be so small that it may, in general, be safely neglected; if further refinement is desired it can readily be allowed for. The various parts subject to thermal expansion are not of equal dimensions nor of equal capacity for heat, so that if the temperature of the surrounding air change rapidly the temperature correction is not valid. This is the case with any mercury barometer, so that the exposure should be one where rapid variations of temperature do not occur.

CONSTRUCTIONAL DETAILS

Referring to Fig. 1, the glasswork on the left consists of a barometer tube with an upper and lower reservoir, of which the upper is exhausted of air and sealed by the U-tube on the extreme left, while the lower is open to the atmosphere. It is essential that both reservoirs should be of uniform bore and that, as far as possible, the bore of each should be the same. A small glass bell, which is shown in detail in Fig. 4, floats mouth downwards on the surface of the mercury in the lower reservoir, and the air which is trapped beneath it provides, by its expansion with temperature, a compensation which approximately neutralises the effect of the temperature expansion of the mercury and other parts of the apparatus. The glass bell is surmounted by a glass stem which is supported in a steel tube to which is attached a suitable balance weight and an upward extension in the form of a thin steel rod. The balance weight is so proportioned that the float is pressed down into the mercury by a load of about 10 grammes more than its own weight.

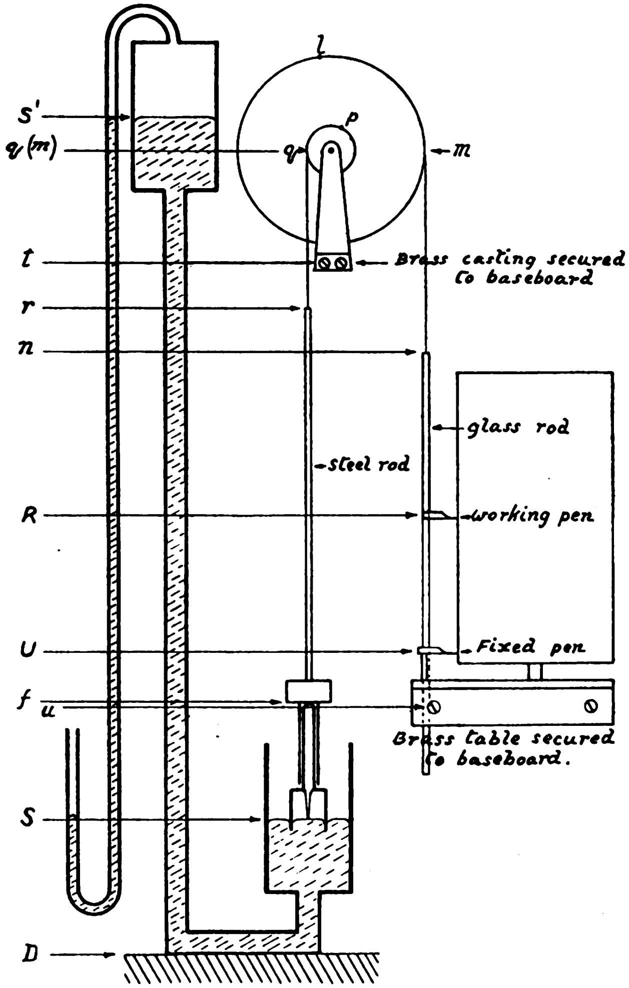
S'
q (m)
l
p
q
m
t
Brass casting secured to baseboard
r
n
glass rod
Steel rod
R
working pen
U
Fixed pen
f
u
Brass table secured to baseboard.
S
D

Fig. 2.—Float Barograph.
Diagrammatic drawing of the working parts.

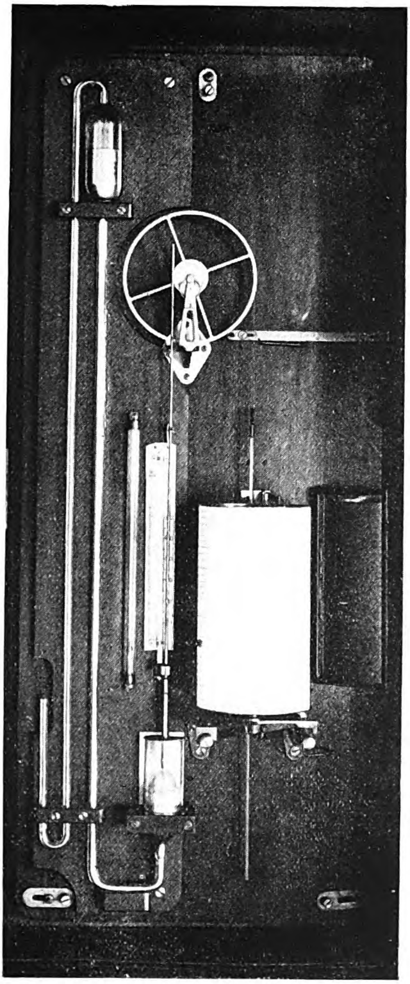

FIG. 1.--The Dines Float Barograph.

A prominent feature of the instrument is the large aluminium wheel above the clock drum. It is fitted with small steel pivots which rest on brass rollers so as to reduce the frictional resistance of rotation to a minimum. The details of this bearing are shown in Fig. 3. The wheel is made in the form of two co-axial pulleys, usually of relative diameters about 4 to 1, and all the moving parts are hung from them by means of very thin platinum wires. On the left hand side, as may be best seen in Fig. 2, two wires *r q p*, about .10 mm. in diameter are fixed at a point *p* near the top of the small pulley and are wrapped round it to the left and thence hang down and support the unbalanced part of the weight of the glass bell and the steelwork above it. Actually, the steel rod *fr* is continued upwards far enough for it to rest lightly against the pulley at *q* which serves to keep it in its place without setting up friction (see Fig. 3). It is evident that the pulley must be so placed that the glass bell when unconstrained shall be co-axial with the lower reservoir. If nothing were interposed between the bell

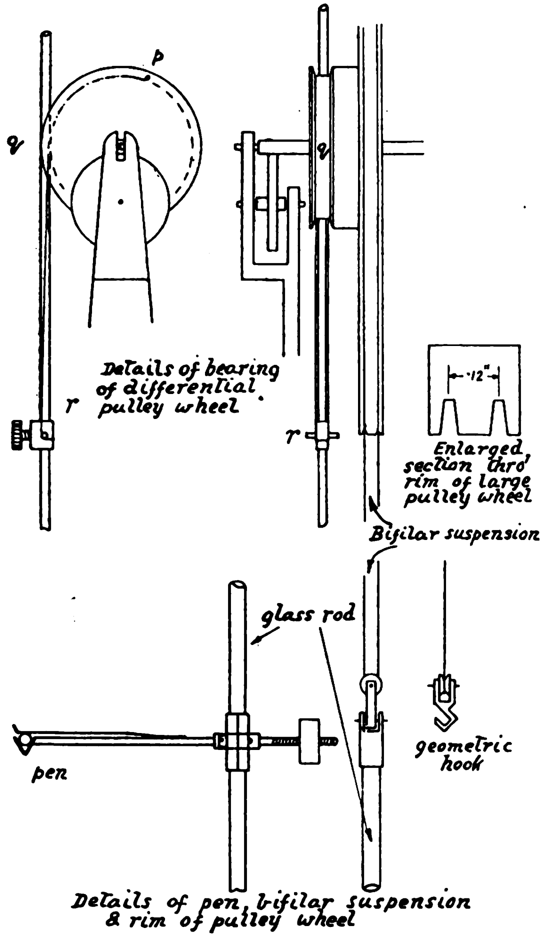
p
q
q
r
r
Details of bearing of differential pulley wheel
·12"
Enlarged section thro' rim of large pulley wheel
Bifilar suspension
f
glass rod
pen
geometric hook
Details of pen, bifilar suspension & rim of pulley wheel

FIG. 3.—Details of the mechanism

and the interior walls of the reservoir, however, capillary action would tend to displace the bell into contact with the walls, even if quite accurately hung. This tendency is overcome by floating a ring of steel balls on the mercury between the bell and the walls of the reservoir.

On the right hand side of the large pulley another similar pair of platinum wires $n\,m\,l$, .075 mm. in diameter and 3 mm. apart are fixed at l near the top, and are wrapped round the pulley to the right and thence hang down and support a long thin straight glass rod nR on which is fixed the pen arm and a corresponding balance weight. The details of this part of the moving system are shown in Fig. 3, and it will be seen that the two wires form a bifilar suspension by means of which the necessary pressure of the pen on the paper is provided. The pressure of the pen is arranged to be very light, in fact as light as is consistent with its proper action. Ideally the pen system needs no further constraint, but for the sake of definiteness, and particularly to ensure accuracy in the time co-ordinate of the barogram, the glass rod is allowed to rest near the top and bottom ends in two open guides, which are so adjusted that the pressure between them and the rod is very small.

The movement of the free mercury surface in response to changes of pressure at any temperature is half that indicated by a standard Fortin barometer at the same temperature. The magnification of the movement between the float and the recording pen is equal to the ratio of the effective radii of the two parts of the differential pulley. This is usually made equal to about four, and hence the scale value of the record is about twice that of a standard Fortin barometer. As will be noticed later, a correction has to be made to this on account of the action of the air beneath the float, which has the effect of increasing the scale value by about five per cent. at the most.

The clock turns about a vertical spindle which is mounted on a sliding table running on horizontal guides fixed to the baseboard of the instrument. By this means, the drum and table can be pulled straight away from the pen system, which is somewhat to the rear of the drum, and the process of changing charts does not interfere with the pens. To provide datum lines from which to tabulate the barogram two fixed pens are provided, one at the top and the other at the bottom of the drum; the lower one only is shown in Fig. 2. The reason for providing two datum lines is so that a check may be available on any expansion or contraction of the chart which may take place between the time at which the record is made and that when tabulation takes place; this point is dealt with in greater detail in the second part of the paper. The usual type of pen lifter is provided to move the three pens away from the chart when required. The pen nibs employed are fine mapping pens which are clipped into horizontal vee grooves in the holders. When a pen is changed, the new nib will fit closely into the same position as the old one and the risk of an appreciable change of zero occurring is small. Such pens will work for a long time without renewal in an instrument of this kind.

Fig. 2 explains in detail the arrangement of the glasswork, float and other moving parts. The baseboard is made of seasoned varnished wood (mahogany or teak), and the various fixed parts are secured directly to it. The fixing of the glasswork to the baseboard may be done on two systems:—

(1) Each reservoir may be independently secured in a suitable wooden cradle, in which case differential expansion between the wood and glass will cause an undesirable strain on the latter.

(2) Both reservoirs may be so supported that relative vertical motion between them and the baseboard is possible, while the weight of the whole is taken on a support placed below the horizontal portion of the glass tube at the bottom.

The latter system is probably the better on the whole and Fig. 2 shows a support of this kind. The index letters on the left hand side of Fig. 2 are placed at the same levels as the points of the apparatus which they represent, so that the length of *fr*, for example, gives the actual vertical distance between the points *f* and *r* of the instrument.

A table of the leading dimensions of the instrument is given below:—

	cm.
Internal diameter of reservoirs	4.25
Internal diameter of glass tube	0.80
Length of cylindrical portion of upper reservoir	7.50
Diameter of large pulley	15.00
External diameter of glass float	2.85
Distance *DS* in Fig. 2 for instrument working at mean sea level ...	10.00
Distance *Dt*	65.00
Distance *tq*	8.00

FILLING AND ADJUSTMENT

It is impossible to transport the instrument with the glass system filled with mercury. The filling must be done at the time the instrument is installed and it is therefore desirable to describe the process in detail. The operation is simplified by the use of the small piece of apparatus shown in Fig. 4; *p* is a glass tube with a short piece of rubber tube *r* at the lower end and a length of about three feet of rubber pressure tubing and a funnel at the upper end; *r* is inserted tightly into the barometer tube at the bottom of the reservoir as shown, and the whole is clamped securely in position by means of string. The funnel, filled with clean dry mercury, is held at about the same level as the reservoir and then raised slowly, being occasionally lowered temporarily to remove bubbles. The process is continued until the upper reservoir is full and the mercury flows down the sealing tube on the left in an uninterrupted stream. The funnel is now carefully lowered until the mercury falls slightly in the upper reservoir, and on again raising it gently, the mercury should make contact with that in the sealing tube with a sharp metallic click. The tube *p* and rubber *r* are now carefully removed and the mercury will take up its appropriate level in the two reservoirs. It is important to keep the funnel constantly filled during the above process or considerable trouble will be caused by air entering with the mercury.

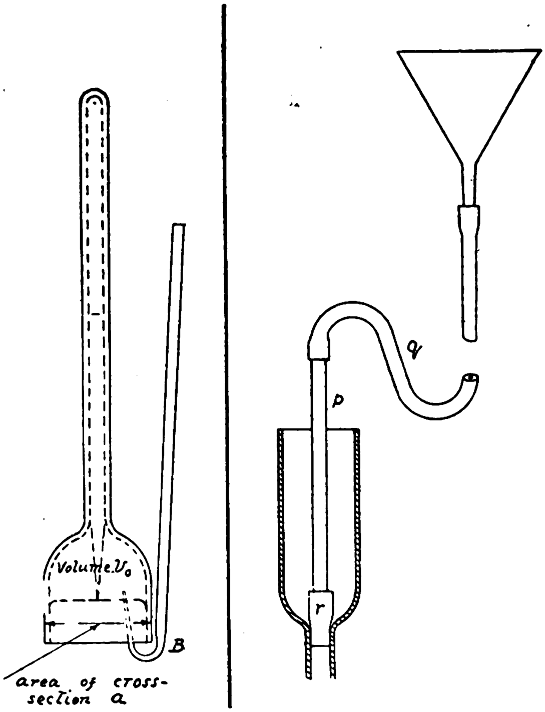

Fig. 4.—Glass Float and apparatus for filling with mercury.

For this reason it is necessary to have at hand rather more mercury than is actually required for filling the glass system, say about 20 per cent. more. Before filling, the glass and filling gear must be thoroughly dried internally by drawing hot air through them; the mercury also should be dried and heated to about 45°C. It is advisable to filter the mercury through a paper funnel containing a small quantity of plaster of Paris which readily absorbs impurities of a moist or oily nature. The glass system is mounted on a separate baseboard, and the whole may readily be removed from the instrument case for convenience in filling.

When the required amount of mercury has been poured in and a satisfactory vacuum obtained in the space above it, there remains the final adjustment of the correction for temperature. In Fig. 4, inside the glass bell float is shown an index pointer which is intended to indicate the level of the mercury at mean temperature and pressure under correct adjustment. Since the volume of the air beneath the float is dependent on both pressure and temperature, the adjustment must be made under known conditions and it is convenient, if possible, to make it under approximately average conditions of both elements. The process is as follows:—

Dry the float thoroughly and set up the instrument under working conditions except that the maximum possible amount of air is left beneath the float and that some of the steel balls are removed from the reservoir. Obtain a piece of fine glass tubing and draw the end down to a capillary size, then bend the fine end to a U-shape as shown at B in Fig. 4. The U-tube may now be immersed in the mercury in the reservoir and the open end brought up under the float. If the bore be fine enough the mercury will not enter the tube, and as soon as it rises above the surface air will flow out through the tube from under the float. The process is stopped as soon as the level of the mercury inside is correct.

From a knowledge of the dimensions and coefficients of expansion of the various parts of the apparatus, it is possible to calculate the correct amount of air beneath the float in order to obtain the best possible compensation for temperature. Details of the computation are given in the second part of this paper. Owing possibly, however, to uncertainty in the value of the coefficient of thermal expansion of wood, or perhaps to the presence of a little air in the space above the mercury, it is not usually possible to obtain perfect compensation by calculation alone, and if greater refinement is desired it becomes necessary to measure the residual error when the instrument has been erected and set to work. The easiest way to do this is to make a long series of comparisons between a standard barometer and the barograph, taking the temperature of the latter at each observation. The observations should be made, if possible, at times when the temperature is not changing rapidly, preferably soon after a maximum or minimum, and should extend over a long enough period to cover a considerable range of temperature.

One may now regard the reading of the barograph as a function of pressure and temperature and determine the regression equation between them. In practice, a less laborious method is to plot the readings of the barograph against pressure without regard to temperature and thence obtain the scale value of the record. Next, suitable groups of observations must be selected in which the temperatures are extreme either way and each group meaned. Provided that the mean pressures in each group are not greatly dissimilar, the scale value already determined may be used to correct for difference in mean pressure between the groups, and then the effect of difference of temperature may be determined. The quantity of air beneath the float must now be altered to suit. As the scale value will be altered at the same time, a suitable correction must be applied to the value previously determined.

Owing to the uncertainty in the behaviour of wood with regard to change of temperature, and the further consideration that it is also not independent of the relative humidity, it would be of advantage to construct the instrument with a metal frame instead of a wooden one. All that is essentially needed is a metal connexion between the supports of the pulley wheel, the supports of the recording drum and fixed pens and the lower part of the wooden baseboard. The connexion at the level of D must be rigid, but in the upper parts provision must be made for slight relative expansion between the wood and metal by means of oval bolt holes, for example. Since the thermal expansion of suitable metal is much greater than that of wood, this change will tend to increase the amount of the necessary compensation, but as will be shown in the second part of the paper, the defects of this are small compared with the advantages likely to be obtained.

If it is desired to make time marks on the barogram, either by hand or by an electrical system, the usual procedure is to provide a moving piece in the form of a stroker which acts on the circumference of the large wheel. Details of an electrical system are given in a paper in the *Quarterly Journal* for October, 1924.[1] Some care is required in designing the device because a fine pen working with a very light pressure on the paper will not leave a mark if moved at other than a very low speed. It is, therefore, necessary to employ an electro-magnet working against a dashpot, so adjusted that the movement is decidedly slow. If, for example, the pen be displaced by about 2 mm. it should take at least two seconds to do so. If the movement be made by hand, a simpler mechanism will suffice, and there is no difficulty in securing a satisfactory mark.

On more than one occasion attempts have been made to get the Dines float barograph made by commercial instrument makers. Unfortunately they seem frequently to find considerable difficulty in turning out a satisfactory instrument if it be of an unorthodox pattern, even though no recondite principles are involved in its construction. It is a pity that such should be the case, and it is to be hoped that in future it will not be necessary to make such a charge against British instrument makers.

PART II.—ANALYSIS OF THE SCALE VALUE AND THE METHOD OF COMPENSATION FOR TEMPERATURE

The procedure adopted will be first to consider the amount of air which must be trapped beneath the float to effect compensation for temperature change at a definite pressure, which may most conveniently be taken as the mean pressure at the station. Secondly, the scale value at a definite temperature, preferably the mean temperature at the station, will be determined. Finally, an expression for the residual error at temperatures and pressures other than the means will be obtained.

Every part of the instrument is subject to thermal expansion and its effect must be taken into account in a complete analysis. It will be convenient first to analyse the movement of the mercury surface S in Fig. 2 with respect to a fixed horizontal datum line through D. It is assumed that the glasswork is, in effect, attached to the baseboard at D and the thermal movement of S may be divided up into two parts and each considered separately. Thus:—

x_1 = The movement of S downward in cm. per degree rise of temperature due to change of density of the mercury, it being supposed that its volume and all linear dimensions of the apparatus remain constant.

x_2 = The movement downward in cm. due to change of volume of the mercury and changes in the linear dimensions of the glasswork.

Secondly, the movement with regard to D of a point at S fixed in the float has to be considered when the distance between the recording pen R and the fixed pen U remains constant. Every part of the moving mechanism and the wooden baseboard enters into the question, and the effect may be again divided up into two parts. Thus:—

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[1] *London, Q.J.R. Meteor. Soc.*, **50**, 1924, pp. 373-380.

x_3 = The movement upward in cm. per degree rise of temperature due to expansion of the moving mechanical parts, the baseboard and supports being supposed invariant.

x_4 = The movement upward in cm. due to the expansion of the baseboard and fixed supports alone, the dimensions of the moving parts being supposed invariant.

The coefficients of thermal expansion of the various substances employed are denoted by the symbols in the following table; their numerical values are given in the right hand column:—

Volumetric expansion of mercury per degree abs.	e_m	182×10^{-6}
Linear expansion of aluminium ,, ,,	e_a	$25\frac{1}{2} \times 10^{-6}$
,, ,, brass ,, ,,	e_b	19×10^{-6}
,, ,, steel ,, ,,	e_s	11×10^{-6}
,, ,, platinum ,, ,,	e_p	9×10^{-6}
,, ,, lead glass ,, ,,	e_g	8×10^{-6}
,, ,, mahogany in the direction of the grain per degree abs.	e_w	4* $\times 10^{-6}$

The following symbols will also be employed:—

V = The volume in cc. of the total quantity of mercury in the working part of the system.

A = The mean horizontal area of the two mercury surfaces S and S′ in cm^2.

H = The height in cm. of the mercury column corresponding with a pressure P mb. and temperature T abs. at the station.

β = The ratio between the effective radii of the two pulleys.

It is assumed that the glasswork is supported at D and that the reservoirs are free to move vertically relatively to the wood behind them. Under these conditions the following relations may readily be proved:—

$$x_1 = +\frac{H}{2} \cdot e_m$$

$$x_2 = -\left\{\frac{(e_m - 3e_g) \cdot V}{2A} + \frac{\overline{DS} + \overline{DS'}}{2} e_g\right\}^{\dagger}$$

$$x_3 = -\left\{\left(\overline{Sf} + \frac{\overline{nR}}{\beta}\right) e_g + \overline{fr} \cdot e_s + \left(\overline{rq} + \frac{\overline{mn}}{\beta} + \text{arc } qp + \frac{\text{arc } lm}{\beta}\right) e_p - \left(\text{arc } qp + \frac{\text{arc } lm}{\beta}\right) e_a\right\}$$

$$x_4 = +\left\{\left(\frac{\beta + 1}{\beta}\overline{Dt} - \frac{1}{\beta}\overline{Du}\right) e_w + \left(\frac{\beta + 1}{\beta}\overline{tq} - \frac{1}{\beta}\overline{uU}\right) e_b\right\}$$

To obtain compensation for temperature, the upward movement of the float relative to the mercury surface S per degree rise of temperature must be equal to the algebraic sum of x_1, x_2, x_3, x_4.

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* The value for mahogany is subject to uncertainty, but is, at any rate, not much greater than that stated.

† Expressions under bars (*e.g.*, $\overline{DS}$) represent vertical dimensions shown in Fig. 2.

The first term x_1 is independent of the details of the instrument and is equal to $(91 \,.\, H \times 10^{-6})$. The other three terms depend on the details of construction and their sum is to be regarded as a definite constant of the individual instrument. Let us denote it by $(b \times 10^{-6})$. It will be seen that b is independent of H.

With the instrument as usually constructed and intended to work at no great height above mean sea level, the approximate numerical values of the three terms are:—

$$x_2 = -\left\{79\frac{V}{A} + 380\right\} . \, 10^{-6} \text{ cm.}$$

$$x_3 = -540 \times 10^{-6} \text{ cm.}$$

$$x_4 = +480 \times 10^{-6} \text{ cm.}$$

where A is approximately 14.2 cm.^{2} and V about 190 cc. Since the mean value of H near M.S.L. is about 76 cm. it is evident that x_1 is much the largest term, and that x_3 and x_4 are small and of opposite sign so that together they are almost negligible. Furthermore, if we can increase V sufficiently we can make x_2 and x_1 largely cancel each other, so that no further temperature compensation is required. To do this it would be necessary to make V/A somewhat greater than H, and while this could be done by using a tube of very large bore between the reservoirs, it would entail a weight of mercury so great as to be undesirable.

Under ordinary conditions, therefore, we may write

$$x_1 + x_2 + x_3 + x_4 = (91 \,.\, H + b) \,.\, 10^{-6} \quad . \quad . \quad (1)$$

where b has a value of about -1500 cm., but strictly requires to be calculated for the individual instrument when set up under the conditions in which it is to work.

Turning now to the float (Fig. 4) it is first to be observed that the pressure of the air beneath it is not necessarily quite equal to that of the atmosphere outside, but that the difference is so small that in calculations involving this air it may be ignored. If then v be the volume of air beneath the float at temperature T and pressure P, and a the area of the external cross section as shown, it follows that a rise of temperature of one degree will cause the float to rise by v/aT. If the mean values of pressure temperature, height of the mercury column, etc., at the site be P_0, T_0, H_0, etc., then for temperature compensation at the pressure P_0 we must have beneath the float under those conditions a volume of air v_0 which is given by the expression

$$v_0 = aT_0 \cdot (91 \,.\, H_0 + b) \,.\, 10^{-6} \quad . \quad . \quad . \quad (2)$$

Let us suppose that the adjustment has been made, so that as long as the pressure remains equal to P_0 change of temperature has no effect whatever. We have next to determine the scale value of the record at a constant temperature T_0. The air beneath the float changes its volume with pressure and this increases the movement of the pen. If the pressure change from P_0 to P the volume changes from v_0 to $\left(v_0 \frac{P_0}{P}\right)$ and the float sinks by $\left(\frac{v_0}{a} \frac{P - P_0}{P}\right)$ relatively to the surface S.

If then y be the movement of the pen as the pressure changes from P_0 to P at temperature T_0 we shall have

$$y=\beta\left(\frac{H'-H_0}{2}+\frac{P-P_0}{P}\,\frac{v_0}{a}\right)$$

where H' is the height of the mercury column at pressure P and temperature T_0.

From this equation a chart may be engraved for use with the barograph. It will be noticed that it is not strictly linear, but the departure therefrom is in practice so trifling that it may be ignored by substituting P_0 for P in the denominator of the second term.

It is now necessary to consider what errors will arise when using the chart at temperatures other than T_0. For perfect compensation at pressure P the rise of the float per degree rise of temperature ought to be

$$\frac{v_0}{aT_0}\,\frac{91\,H'+b}{91\,H_0+b}$$

which follows from equations (1) and (2).

Actually at pressure P the rise per degree will be

$$\left(\frac{v_0}{aT_0}\,\frac{P_0}{P}\right)$$

It follows, therefore, that at pressure P and temperature T the pen will read too high on the chart by

$$\beta\,.\,(T-T_0)\left(\frac{v_0}{aT_0}\,\frac{91\,H'+b}{91\,H_0+b}-\frac{v_0\,.\,P_0}{aT_0\,.\,P}\right)$$

We may for the purpose in question take $P=13.31\,H$ without serious error and ignore the variation with temperature which strictly exists; also the scale value may be taken at the approximate value of $\beta/2\,.\,1/13.31$ cm. per millibar. The expression above then reduces to

$$\beta\,.\,(T-T_0)\,.\,\frac{v_0}{aT_0}\,\frac{(P-P_0)\,[6.84\,(P+P_0)+b]}{P\,(6.84\,P_0+b)}$$

that is

$$26\,.\,62\,.\,(T-T_0)\,(P-P_0)\,\frac{v_0}{aT_0}\,\frac{6.84\,(P+P_0)+b}{P\,(6.84\,P_0+b)}\ \text{mb.}$$

on the chart.

It is not possible to assign precise numerical values to this expression unless the details of the instrument are known. Taking the worst possible case, that of an instrument working at M.S.L. and giving b the approximate value of -1500 applicable thereto, the corresponding value of v_0/aT_0 will be .0054 from (2).

The expression for the error now becomes

$$.144\,(T-T_0)\,(P-P_0)\,\frac{6.84\,(P+P_0)-1500}{P\,(6.84\,P_0-1500)}\ \text{mb.}$$

This may be further simplified by taking P_0 as 1014 mb. and substituting P_0 for P in the denominator and in the term $(P+P_0)$. The final expression is $3.22\,(P-P_0)\,(T-T_0)\times 10^{-4}$ mb., the meaning as regards sign being that when the error is positive the instrument reads too high.

The expression just obtained is shown plotted in the form of isopleths in Fig. 5, and it will be seen that for all practical purposes it is negligible.

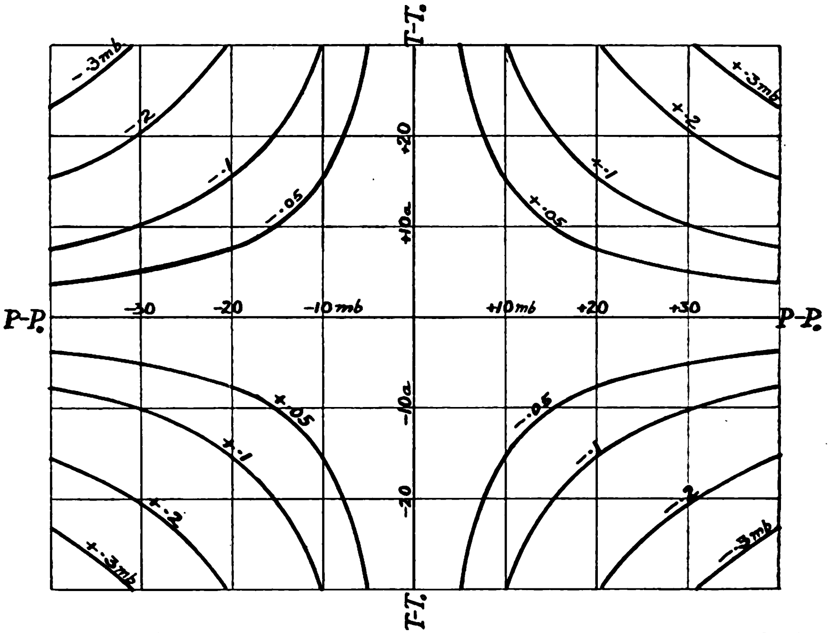

FIG. 5.—Isopleths of Residual Error for compensated Barograph at mean sea level.

If the instrument be constructed with a brass frame, as suggested in the first part of the paper, the calculations will be affected only in the term x_4. Instead of the value $+480 \times 10^{-6}$ found above, the new value would be $+1620 \times 10^{-6}$. This would alter the value of b to -360 cm., and from (2) it appears that v_0 under the conditions of mean sea level will be increased by about 20 per cent. of its former value. Such an increase is not serious and is worth incurring to avoid the uncertainty introduced by the presence of the wooden frame.

A possible source of error in tabulating the records arises from the fact that paper charts may have a coefficient of expansion with temperature and certainly are very susceptible to changes in the relative humidity. By the provision of two datum lines near the top and bottom of the record respectively, it is possible, if desired, to allow for this. If the true distance apart of the two fixed pens under average conditions of temperature be s and if, when the record is tabulated, the distance between the two datum lines be found to be s', then, in order to determine the true distance of the working pen above the lower datum at any point, the measured ordinate must be multiplied by the ratio s to s'. It should be noted that the true distance between the fixed pens is itself dependent on temperature, but even in the worst possible case the variations are below the limit of accuracy attainable in reading the record and may be neglected.

It has been mentioned previously that sudden changes of temperature are not compensated, and it will be well to form an estimate of the error which may be introduced by this means. If the air surrounding the instrument suddenly changes its temperature by 1a. the first effect will be that all the moving mechanical parts, which are small and light, will quickly approximate to the new temperature. The air under the float will follow next, but as it is in contact with the mercury and protected from the surrounding air as well, it will be more sluggish. The mercury and the frame will be the last to take up the new temperature. If, therefore, we assume that a stage is quickly reached in which the moving mechanical parts have increased in temperature by 1a. and the air under the float by ½a., while the mercury and the frame remain almost unaltered, it would seem probable that the maximum possible error will be produced. This is equivalent to a movement of the pen downwards given by $\beta\left(\frac{v_0}{2\,aT_0} - x_3\right)$

Using the same values of the various quantities as before, this reduces to .013 cm. or .086 mb. The sense of the movement is that a rise of temperature makes the pen read too low.

DISCUSSION.

Sir **Richard Gregory**: Mr. Dines has described to us a remarkably fine instrument, the construction of which represents scientific design of high standard. The records which he has shown to us are very clear, and they enable small variations of atmospheric pressure, periodic or otherwise, to be studied in detail. The instrument is a precise and refined development of the old-fashioned clock or dial barometer. The simple method of compensating for temperature variations by means of the small glass bell in which air is trapped is particularly ingenious and effective. Here again, by adopting the principle of expansion in different directions we are reminded of the Graham mercurial pendulum and the gridiron pendulum used for similar compensating purposes in clocks. The magnification of the movements of the mercury in the reservoir is probably sufficient for practical use, but it would, of course, be possible to increase this if necessary. Sir Jagadis Bose, in his studies of movements in plants, has shown how to magnify such movements a million times, and the same principle might be applied to the movements of a barometric column if there were any useful object to be attained in doing so. As reference has been made to instrument makers in connection with the construction of novel instruments of this kind, I will ask Mr. H. W. Baker if he will favour us with some comments upon the paper from this point of view.

Mr. H. W. **Baker**: Speaking from the point of view of the practical instrument maker, I have personally made six of these instruments, while two or three others have been made by an outside firm. Of these latter one appeared to be satisfactory, but the most recent specimen suffered at first from unsuitable workmanship though this was rectified when the faults were pointed out. With the exception of one or two parts of the instrument there is no need for a greater degree of accuracy in making and assembling the Dines float barograph than is required in any other well-made piece of apparatus, in fact too accurate fitting may be a mistake. Instrument makers frequently err on the side of allowing too small clearance between moving parts, and such a thing might easily occur in this case in the bottom reservoir where anything like a close fit between the float, the steel balls and the walls is most undesirable. The same applies to the fit of the stem of the float into the steel sleeve.

A point where great accuracy is necessary occurs in the double pulley, which must be accurately turned both centrally and laterally. As a matter of fact when an instrument is to be constructed on a principle suggested by someone else the actual maker always encounters difficulties which are not apparent even in well ordered drawings, and very often parts have to be remade and the design altered; the same thing may happen even when a model is provided to work from. In the instrument in question, the glass parts ought always to be made first, as the mechanic may need to alter some of the dimensions in order to conform to inaccuracies on the part of the glass-blower.

A few notes describing the instrument and its method of working in general, and the parts in particular, and giving brief reasons for the use of certain materials are of great assistance; with their aid there is no reason why a good firm should not make a satisfactory job of the instrument, especially after they have gained experience in the making of their first specimen. It is certainly desirable, if possible, for the designer to supervise the manufacture of the first if errors are to be avoided.

Mr. J. E. CLARK inquired whether the vertical scale used was held to be the most satisfactory. At first glance of the exquisite traces passed round, one feared whether some of the minuter undulations could be easily measured on the scale of two to one. That, for London at least, required at most nine inches in height. From the nature of the apparatus double that scale would apparently be feasible, if such proved to be preferable.

Dr. F. J. W. WHIPPLE said that the success of the float barograph was due not only to the delicacy of the mechanism but also to the generous size of the upper and lower cisterns. The errors which occurred with mercury barometers provided with small tubes were eliminated. The defect in photographic barographs such as had been in use for nearly sixty years at the observatories of the Meteorological Office could be demonstrated by tapping the tubes occasionally. If pressure was rising when the tube was tapped, then a step appeared on the developed photographic record. No such step was caused by tapping the instrument when pressure was falling. On the other hand, when the float barograph pin was disturbed it recovered its position exactly. By taking the Dines instrument as a standard it was found at Kew Observatory that the diurnal range of pressure recorded by the photograph was too small by an appreciable amount. The range of the diurnal inequality and of its harmonic components were similarly affected, the errors being of the order of five per cent. There were few parts of the world for which the diurnal inequality of pressure had been determined with the precision that was desirable. He hoped that any difficulties in the way of manufacture of the float barograph would be overcome as it was an instrument which should be widely used.

Mr. E. G. BILHAM said that he was personally very interested in the paper, more particularly because he had discussed some results obtained with the barograph eleven years ago.[2] In that paper he had stated that a description of the instrument was "about to be published" and he welcomed the fulfilment of that anticipation, though rather belated. In the course of the investigation the temperature compensation of the barograph was found to be practically perfect over a wide range of temperature. He felt bound to point out a source of error that had not been mentioned, viz., that resulting from irregularities in the diameters of the upper and lower cisterns. In making these, a uniform piece of tubing should be selected and cut in two, using one half for the upper and the other half for the lower cistern. To get uniformity in scale value with 0.1mb. the mean diameters of the two cisterns must agree to within less than .01 inch. For this part of the instrument the maker was at the mercy of the glass-worker who would find it extremely difficult to meet these exacting requirements. When the instrument was used at an observatory, however, this objection would be of no practical importance, since the method of "residual corrections" would naturally be used in evaluating hourly readings from the traces. Also, care would be taken to guard against sudden changes of temperature of the magnitude envisaged by Mr. Dines.

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[2] "The diurnal variation of atmospheric pressure at Benson, Oxon, during the year 1915." *Q.J.R. Meteor. Soc.*, **43**, 1917, pp. 269-281.

The method of putting time-breaks on the photographic barograms had been found to introduce a spurious 2-hourly oscillation in the hourly tabulations. This source of error would not arise with the float barograph.

Some criticisms had been passed upon firms of instrument makers. In his (Mr. Bilham's) experience the makers were very willing to do their best to meet the most exacting requirements when the need for them had been carefully explained. By writing this very complete and valuable description of the float barograph Mr. Dines had done a great deal to ensure that satisfactory instruments would, in future, be forthcoming from the trade. Similar descriptions of other instruments would be welcome.

Sir GILBERT WALKER alluded to the difficulty found at times when an automatic barometric record of a month or more at a mountain station is required, and asked whether Mr. Dines's instrument could be modified to meet the need. He also asked how far its readings were reliable in accuracy.

Mr. J. H. FIELD (*communicated*): The need of equality in sectional area for the two reservoirs has been emphasised, but it is not clear why so expensive a requirement should be imposed on the makers: it should be sufficient to have each reservoir uniform in area over its mercury range. In any case each instrument of this high class would have its own scale of ascertained corrections; and for use with a standard ruled chart and standard mechanical magnification, the non-standard magnification at the mercury surface, imposed by variations of area ratio in different instruments, would lead merely to larger corrections and not to less final accuracy. If, however, equality of area is really desired, the least expensive way to secure it would probably be to use for the lower reservoir a tube of slight area-excess, and finally to adjust to equality by fixing a vertical wire of suitable gauge against the internal face of the lower reservoir. The wire would be small in diameter compared with the floating steel balls and these would ride up and down as freely as they do now, while any existing capillarity hysteresis would not be appreciably increased by the wire. The open reservoir could be ground cylindrical over its range at small cost, thus reducing any present irregularity of scale; and a maker would probably agree that the upper one could similarly be trued up before being drawn out at its two ends.

Whether this reservoir is trued up or left irregular as at present, it must be long enough to ensure that its working range is unaffected by the subsequent blowpipe work, so that no obvious objection lies in the way of internal grinding and polishing.

In regard to the question raised by Sir Gilbert Walker, the feasibility of meeting the need for a long-period record from an unattended barometer, there should probably be no serious difficulty involved. A high-level observing hut in India (Chôr Peak, 12,000 feet) used to be personally attended for some nine months in the year, and closed for the remaining months as being snow-buried. The station was abolished, but at one time a long-period drive was contemplated to cover the winter season, and a hopeful method was tried in a preliminary manner in Simla in anticipation of use on the Chôr. The drive was to be by a large float following the fall of the surface of kerosene oil in a long cylindrical container from which the oil slowly escaped through a capillary, at the bottom of a long vertical tube, into a storage tank below. The movement was to average one inch per day, varying slightly with changing head of oil and changing viscosity, but for the purpose then in view the timing would have been satisfactorily provided by the daily maxima and minima of the record. In the trial apparatus a smoked aluminium sheet received the record from a gate-pen operated from the open reservoir of the barometer.

Present-day electric clocks offer, possibly, another solution. A Bulle electric clock now in my charge is stated to have gone for four years continuously on its single small dry cell; and for an earlier but somewhat similar type of clock (Holden), measurements are stated to have shown that consumption is no more than two watt-hours per year of running.

Mr. L. H. G. Dines: In reply to Mr. Clark, the further doubling of the scale value would not have quite such merits as might be thought because it must involve an increase in the effect of friction which would tend to neutralise the advantage gained.

Dr. Whipple had pointed out an omission in the paper in that the freedom from trouble due to capillarity, though mentioned, was not stressed as much as perhaps it might have been.

Mr. Bilham and Mr. Field had indicated a weak spot in the instrument. The large glass tube from which the reservoirs are made has never been quite uniform in bore along its length. Inequality as between the two reservoirs does not in itself matter provided that the respective cross sections are constant throughout the working range; in practice that is not likely to be the case and all that has been done heretofore is to specify to the glass-blower that the same piece of tubing should be used in making both reservoirs, that it should be of as uniform bore as possible, and that if the reservoir be of a slightly conical shape the larger ends should both be upwards or both downwards. I understand that large glass tubes cylindrically ground internally can now be obtained, and this should entirely obviate the difficulty for the future.

In reply to Sir Gilbert Walker the chief difficulty in making the instrument run for a month without attention would be with the pen, but with a larger drum turning once per month, and if extremes of relative humidity were not experienced, it is probable that quite good monthly records could be obtained. With regard to the accuracy of the record a long comparison had been made more than once between a standard Kew pattern barometer and a float barograph. Speaking purely from memory he thought that a standard error of about 0.1mb. or a little bit more had been found. It must be remembered, however, that not the whole of this must be laid at the door of the float barograph since the eye readings of the Kew barometer are also subject to a casual error.

Sir RICHARD GREGORY: I am sure you will agree with me that our best thanks are due to Mr. Dines for bringing before us, after so many years, this account of his father's float barograph. In connection with the inquiry whether an instrument of this kind might be made to record continuously for months, I suggest that instead of the recording drum a tape might be used, like that on a tape machine, and there would then be no difficulty as to the size of the drum.

Meteorological Conditions during the First Flight Across the Tasman Sea.

Fellows may be interested in an account of some electrical and other effects observed by Squadron-Leader Kingsford Smith and Flight-Lieut. Ulm and their companions during the first crossing of the Tasman Sea from Australia to New Zealand.

The trough of a rather intense depression of the inverted V type had crossed the east coast of Australia during the day of the 10th September, 1928, on which the start was made. I am indebted to the Commonwealth Meteorologist, Mr. H. A. Hunt, for copies of the Australian morning weather reports (Fig. 1). The only thunder associated with the trough line of the depression in Australia appears to have been reported from Robe and Cape Northumberland on the coast near the Victorian and South Australian border. The rainfall was only light and in New South Wales confined to scattered showers on the northern and southern tablelands. The start from Richmond, a little north of Sydney on the New South Wales coast, was made at 17.25h., at 17.42 the coast line was crossed at

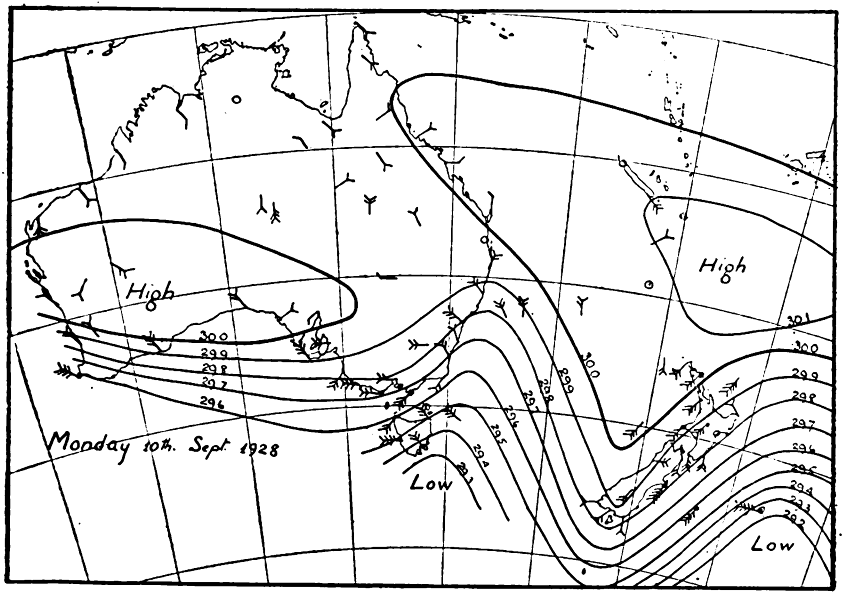

FIG. 1.—Distribution of pressure and winds on the morning of September 10, 1928.

an altitude of 3,200 feet and a speed of 76 knots. The sky was apparently partly cloudy and the visibility rather low, at 19.50h. a very high cloud bank was seen ahead and at 19.55 lightning could be seen. At 20.45h. the altitude was 5,400 feet and the machine was climbing. It was commencing to be very bumpy. At 22.00h. the altitude was 8,000 feet and three separate thunderstorms were visible. The aviators were hoping to pass over the storm ahead of them. At 22.10 no rain had been experienced, but the lightning flashes were becoming blinding. At 22.15 heavy rain was encountered, the altitude being 6,800 feet. The lightning flashes were very close. Bands of light encircled the propeller tips, being about 9 to 12 inches wide round the centre and narrower on the outside propellers. The light round the centre propeller appeared to be bluish in colour. Occasionally the glow extended right to the hubs of the propellers. It would disappear after the lightning discharges and gradually recover. On two occasions the searchlight (30 volts, 1,500 watts) was lit up by the current passing through it. The following hour was the worst experienced. Ice, apparently from supercooled rain-drops, formed on the wind shield, the undercarriage, the engine bearer shafts and the wing itself. It was subsequently estimated that at one stage the machine carried half a ton of ice. Hail was met with at times and the leading edges of the propellers, which consisted of a compressed cotton fabric, were badly torn by it. It became very wet and cold in the cockpit. At 00.15h. there was a calm interval with improved weather. At 00.20 another very severe rain and lightning storm was encountered. Terrific bumps were experienced, vertical velocities of 3,000 feet per minute being recorded. On one occasion there was a fall of 300 feet. The ice on the wings became thicker, and in very severe bumps the plane was forced down from 7,000 feet to 2,000 feet. At 00.30 it was fine again and stars were seen. At 00.40 heavy rain and very severe bumps were again encountered. Ice remained on the machine and it was bitterly cold; the altitude was then 8,000 to 6,000 feet. At 01.45 the worst weather was past, but few stars were seen, several showers of rain were passed and the wind shield could not be kept free of ice. From 03.30 fairly good weather and visibility were experienced, but with almost continuous low cloud. The altitude was maintained at 6,400 feet. At 05.20 land was seen below through a small opening and a descent made through the scud. The land was near Farewell Spit, an excellent offing having been made. An average following wind of nearly 30 miles per hour had been experienced. In Cook Strait it was blowing half a gale from the north-west, and the air was still bumpy. A landing was made at the Wigram Aerodrome near Christchurch at 07.50. Times are all eastern Australian times. When the thunderstorms were first met, and before the 500 feet wireless aerial could be wound in, a discharge passed through it and damaged the 600 metre wireless set.

At 09.00 the trough line of the depression through which the aviators passed was about longitude 164°E., and a cyclone was developing in the northern portion, about latitude 36°S.

Possibly, electrical effects similar to those recorded have been experienced by other aviators, but I have seen no accounts of them. The elucidation of the precise causes offers an interesting problem.

EDWARD KIDSON, *Director.*

Dominion Meteorological Office,
Wellington, N.Z.
October 12, 1928.

THE DISTRIBUTION OF THE AVERAGE SEASONAL RAINFALL OVER EUROPE

By JOHN GLASSPOOLE, M.Sc., Ph.D.

[Manuscript received November 22—Read December 19, 1928.]

INTRODUCTION

In no part of Europe is the precipitation uniformly distributed among the seasons. The average fall of the various seasons does not vary markedly in parts of the Central Plain and in the British Isles, but along the southern fringe of Europe, the summer is practically rainless. Maps of the seasonal rainfall are available for the British Isles,[1] but the extension of the maps to cover the whole of Europe does not seem to have been carried out previously.[2] For this purpose average monthly values have been used for some 650 stations, of which about 200 are in the British Isles.[3] In the case of the British Isles and Germany the average is for the period 1881 to 1915, and elsewhere usually for 30 to 50 years. The data are ample in northern, central and western Europe, but less so in south-eastern and eastern Europe. In the latter region the run of the lines on the maps of this paper must therefore be considered to be liable to some slight modifications when more data are available. The monthly averages at each station have been expressed as a percentage of the annual average and grouped in seasons. Section 2 deals with the fall of the winter half-year (October to March); Section 3 with the fall in the four seasons: spring (March to May), summer (June to August), autumn (September to November) and winter (December to February); Section 4 with the fall of the typical winter month January and the typical summer month July and Section 5 with the variation in the range of the average monthly rainfall amounts across Europe.

Eight maps are reproduced in the paper. On Fig. 1 the positions and names of certain towns are given, but on the subsequent maps the names are omitted and only the positions are shown.

2. THE RAINFALL OF THE WINTER HALF-YEAR

The rainfall of the winter half-year, October to March, is of particular interest in that during this period the evaporation is relatively small, the bulk of the rain going to feed streams or being stored underground. The distribution is shown in Fig. 1. The lines representing 40 and 30 per cent are broken, and the 50 per cent is thickened. The 50 line denotes the region where the winter and summer falls are equal. The fall of the winter half-year in the British Isles is everywhere greater than that of the summer except in three small areas along the east coast, where the summer fall is slightly greater. In the north-west of Scotland and in the south-west of England, Wales and Ireland, the fall exceeds 60 per cent of the annual average.

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[1] The Seasonal Rainfall of the British Isles, by Henry Mellish. *Q.J.R. Meteor. Soc.*, **27**, 1901, pp. 78-93.

[2] Four sketch maps are given in Bartholomew's *Atlas of Meteorology* showing the distribution of the rainfall in each of the four seasons over the world by A. Supan. The scale is, however, small and the rainfall of each season is given in actual inches of rain.

[3] The data used were drawn from *Untersuchungen über die Schwankungen der Niederschläge, Berlin*, 1909, by G. Hellmann (where precise details of the averages used are given), from manuscript data in the possession of the Meteorological Office (London) and in the case of the British Isles from the *Book of Normals of Meteorological Elements of the British Isles, Section V*, Meteorological Office Publication, No. 236.

Over the Continent the winter fall exceeds that of the summer in two well-marked areas, viz., to the west of a line from northern Norway to the western Pyrenees and to the south of a line roughly from the mouth of the Rhone to the Crimea. This separation into two zones occurs at the Pyrenees. The percentage fall increases towards the west and south coasts to about 60 per cent along the south-west coast of Norway, the north-west and west coasts of France and part of the north coast of Spain, and to 80 per cent along the Mediterranean. The two areas in the west and the south differ in that while the former has abundant rain at all seasons,

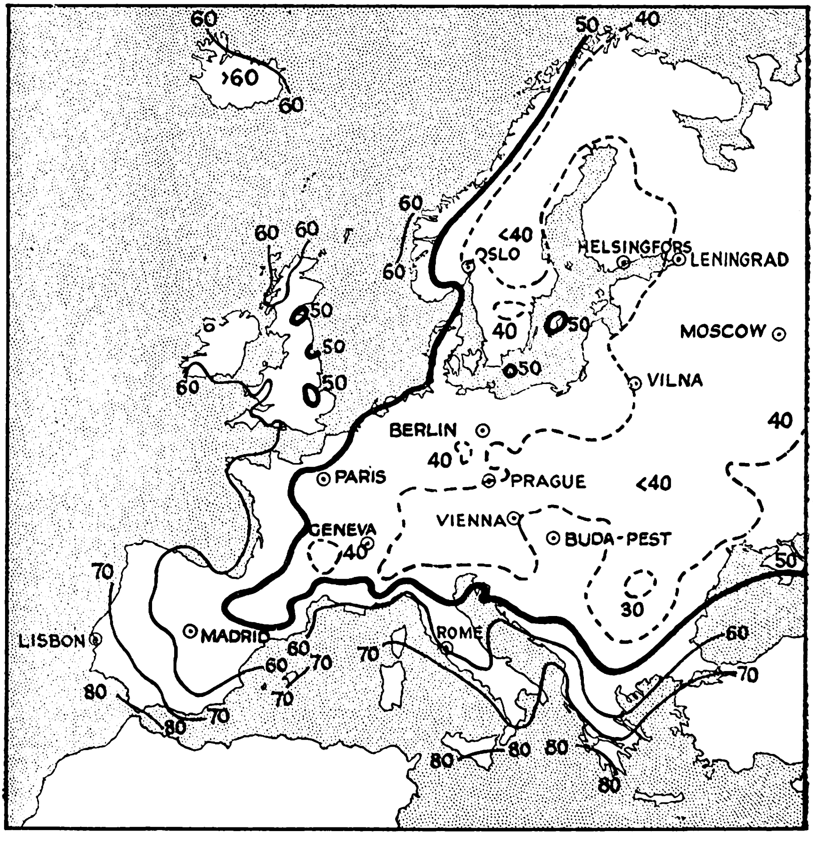

FIG. 1.—Average rainfall of the winter (October to March) as a percentage of that of the year.

the latter receives very little rain in the summer months. Further inland the fall steadily decreases to rather less than 30 per cent in the Transylvanian Alps. The smaller value in the interior of the land masses, occasioned by the increased thunderstorm rains of the summer, is well marked, not only in central districts of Europe, but also in the Iberian Peninsula, Italy, the Balkans and Scandinavia. On the other hand, the fall in the winter is greater on the islands of Bornholm and Gotland in the Baltic than at adjacent land stations. The fall over Iceland is similar in amount to that of the Western Highlands of Scotland and exceeds 60 per cent everywhere except in the extreme north-east.

Some of the extreme values for the percentage fall of the winter half-year are set out in Table I. In addition to the area with less than 30 per cent near the Transylvanian Alps shown on the map, less than 30 per cent also occurs in the Caucasus Mountains and in the Urals, and the value for a station in each of these regions is given in Table Ib.

TABLE I.—AVERAGE RAINFALL OF THE WINTER HALF-YEAR AS A PERCENTAGE OF THE YEAR.

Country, etc.	Station	Fall of winter half-year (per cent of year)
	(a) large values	
Malta	Malta	86
Sicily	Catania	80
Spain	San Fernando	79
Greece	Corfu	79
	(b) small values	
Russia	Vladikavkaz	23
Russia	Pjatigorsk	27
Transylvania	Hermannstadt	28

The lines on the map are everywhere nearly parallel to the coast line, the smallest values being in the interior. The orographical influence is also apparent. We have already noted that the three areas with less than 30 per cent in the winter half-year are mountains. Conversely the Hungarian Plain, in which Buda-Pest is situated, is denoted on the map as an area of relatively large fall in the winter months. This is in striking contrast with the state of affairs in the British Isles where the mountainous regions rather than the plains record a larger proportion of the rain in the winter months. This apparent anomaly is attributable to the fact that the rain falls mainly in different seasons in the two zones. In both zones the mountains receive a larger proportion of the rain in the rainy season.

A map showing the average rainful of the summer half-year, as a percentage of that for the year, is not reproduced since the distribution is simply the inverse of that shown in Fig. 1.

3. RAINFALL OF THE SEASONS.

In considering the seasons the usual grouping of the months has been adopted, viz., March to May as spring, June to August as summer, September to November as autumn and December to

February as winter. It will be noticed that the autumn and winter together include the months September to February, which period differs from the winter half-year already considered by the inclusion of September instead of March. On each map the lines which denote areas where less that 25 per cent of the annual average occurred in the three months are shown broken, so that the areas with less than a fair share of the rain in any season can be seen readily.

(*a*) *Spring* (*March to May*).—The main feature of Fig. 2 is that the range is smaller than in any of the other seasons. It is therefor the simplest of the four maps. The range is from rather more than 30 per cent in the Iberian Peninsula, the Alps and Transcaucasia to less than 15 per cent over a narrow belt from the south to north of the Scandinavian Peninsula. Parts of Spain receive about one third of the year's fall in these three months. Less than 20 per cent of the average falls in the spring over most of northern Europe and also in the extreme south-east, while larger values are found in a broad belt across the southern central districts. In the areas with large spring falls May is often the wettest month of the year. This is the case in areas of about the same latitude in the north of Spain, the north-west of Italy, the Balkans and central Transcaucasia. The May maximum occurs mainly in sheltered valleys where the temperature becomes high relatively early in the year. Further north the continental summer rainfall maximum is usually later. As

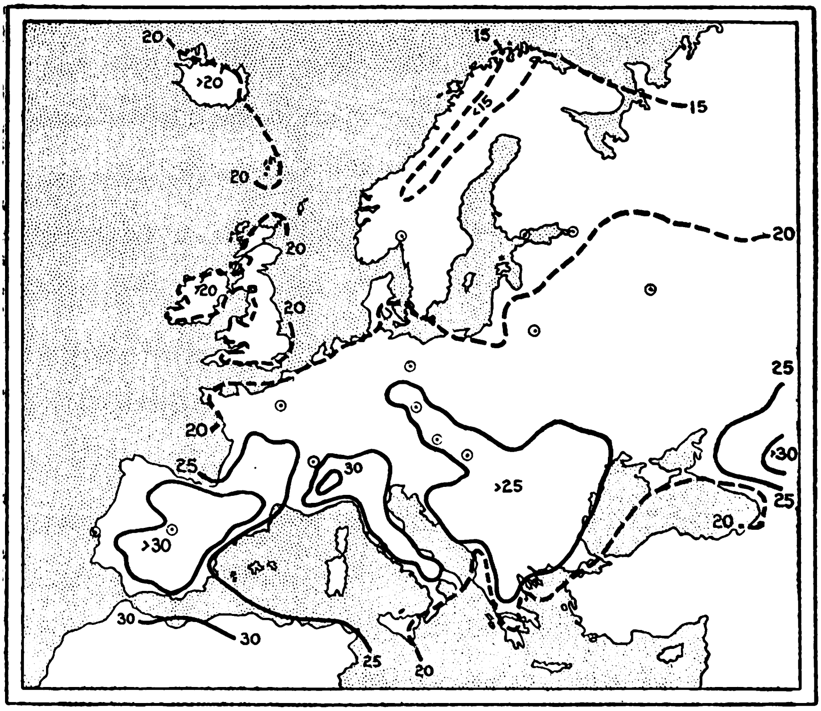

FIG. 2.—Average rainfall of the spring (March to May) as a percentage of that of the year.

much as 32 per cent of the annual average falls in the spring at Melilla along the north coast of Morocco.

Some of the extreme values are set out in Table II.

TABLE II.—AVERAGE RAINFALL, FALL OF SPRING AS A PERCENTAGE OF THE YEAR.

Country, etc.	Station	Fall of Spring (per cent of year)
	(a) large values	
Spain	Madrid	33
Spain	Granada	33
Spain	Burgos	32
Italy	Turin	32
Russia	Vladikavkaz	31
	(b) small values	
Sweden	Jockmock	14
Norway	Sydvaranger	14
Norway	Alten	14

It is of interest in connection with Fig. 2 to recall that the mean pressure[4] during March, April and May is relatively low over the southern Mediterranean region, while there is a ridge of high pressure further north.

(*b*) *Summer* (*June to August*).—The percentage fall during these months is very variable and the map is the most complicated of the four. Along the Mediterranean coast less than one-twentieth of the year's rain falls in these months, while central, northern and eastern districts receive more than one-third and in places nearly one half. In the south July is invariably the driest month while in the north and over much of Germany it is the wettest month of the year. The zone of most rainfall lies farther north in summer than in spring and is sub-divided by the Baltic where the influence of the ocean gives a preponderance of rain in the autumn. In the British Isles the proportion increases from west to east across Ireland and again across Great Britain, the largest values being along the east coast with most land to the west and south-west. The range in the Scandinavian Peninsula is even more pronounced.

The Hungarian Plain is indicated on the map as a region of relatively small percentage fall in the summer months. Similarly further east, in the plain of southern Russia, there is a large area with less than 35 per cent between the Caucasus Mountains and the Urals which receive a much larger proportion in these months.

In the southernmost regions of Europe the probability of one or two summer months (either June, July or August) being rainless has been given by Hellmann and the values are quoted below :—

Station	Country	Probability of summer months without rain	
		one	two
San Fernando	Spain	0.97	0.71
Gibraltar	Gibraltar	0.87	0.37
Catania	Italy	0.78	0.45

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[4] For maps of monthly mean pressure see for example *Manual of Meteorology* by Sir Napier Shaw, Vol. II., pp. 218-241.

Some of the extreme values are set out in Table III.

On the maps of mean pressure for June, July and August the Azores high pressure system is much more developed than during any other month of the year. The wind over southern Europe has a marked northerly component and produces little rain there because it has travelled considerable distances across the land, is essentially stable and is proceeding south and being gradually warmed.

TABLE III.—AVERAGE RAINFALL, FALL OF SUMMER AS A PERCENTAGE OF THE YEAR.

Country, etc.	Station	Fall of Summer (per cent of year)
(*a*) *large*	*values*	
Russia	Ekaterinburg	54
Russia	Nishne Tagilsk	49
Norway	Roros	44
Poland	Pinsk	44
Transylvania	Hermannstadt	44
Sweden	Jockmock	43
Austria	Salzburg	42
(*b*) *small*	*values*	
Gibraltar	Gibraltar	2
Spain	San Fernando	2
Italy	Catania	3
Greece	Corfu	4
Spain	Seville	4
Portugal	Lisbon	4

(*c*) *Autumn* (*September to November*).—The fall of the autumn three months is shown in Fig. 4 to exceed one quarter of that of the whole year over the greater part of Europe. The areas with less than this amount include the central districts, extreme east, and central Scandinavia. In parts of the east of Russia and in Hungary the fall does not reach 20 per cent, but it exceeds 30 per cent along a coastal strip stretching from the extreme north of Norway to Bayonne in France, together with the adjacent areas across the English Channel, the Isle of Man, extreme north-west of Scotland and Iceland; to the south of a line roughly from Valladolid in Spain to the Crimea; in the neighbourhood of the Baltic and White Sea. Rather more than 40 per cent occurs over small areas to the south-east of Spain, *e.g.*, at Melilla in Morocco, Valencia, Marseilles and Mahon in the Balearic Islands. This large fall in the east of Spain is doubtless associated with the marked increase in the frequency of thunderstorms in the autumn, especially in September. Either September, October or November is the wettest month of the year along the west coast of Norway, the east of the British Isles, most of France, Spain and the south of Europe generally. In most places October is the wettest month.

Some of the extreme falls are set out in Table IV.

The main feature of the mean monthly pressure maps for September, October and November is that both the Asiatic high pressure system and the Icelandic low pressure system are well developed. There is therefore a marked increase over the previous months in the flow of moist Atlantic air across western and north-western Europe. The percentage values on the rainfall map

TABLE IV.—Average rainfall, fall of Autumn as a percentage of the year.

Country, etc.	Station	Fall of autumn (per cent of year)
(*a*) *large*	*values*	
Spain	Valencia	43
France	Marseilles	42
Spain	Mahon	42
Albania	Valona	40
Italy	Livorna	40
(*b*) *small*	*values*	
Transylvania	Hermannstadt	18
Russia	Vladikavkaz	19
Bukovina	Czernowitz	20

Fig. 4 are naturally relatively large in the Mediterranean region owing to the small values in the summer.

(*d*) *Winter* (*December to February*).—The fall of the winter three months in the southern Mediterranean is shown in Fig. 5 to reach nearly one half of the annual average. As much as 43 per cent falls in these months at Melilla in the north coast of Morocco. Further north the values decrease to less than 15 per cent over a large area stretching from Switzerland to the extreme east of Russia. To the north-west the values steadily increase and values of more

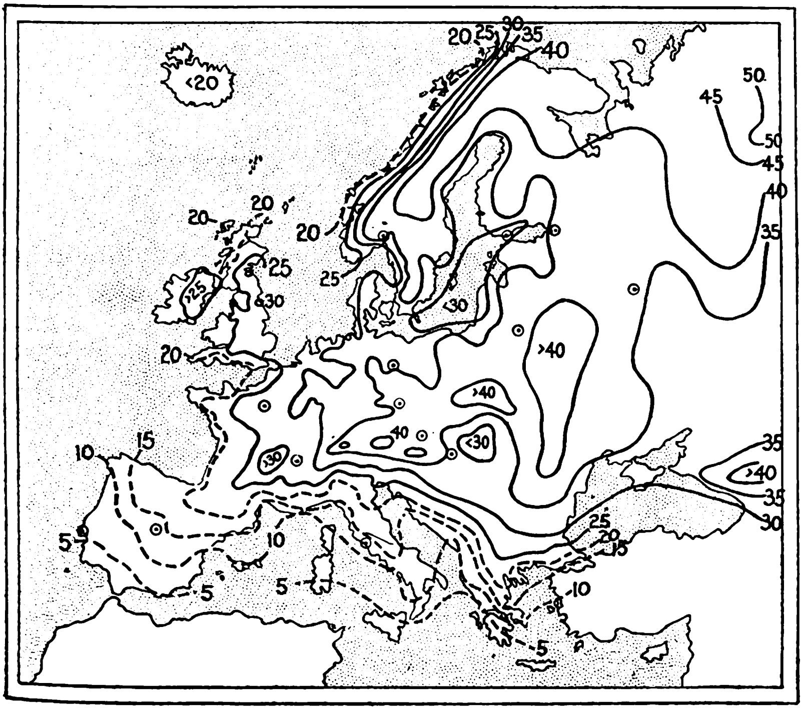

Fig. 3.—Average rainfall of the summer (June to August) as a percentage of that of the year.

than 30 per cent occur over much of the western half of the British Isles, and in parts of Sweden and Iceland. The distribution in eastern Russia is in striking contrast with that shown for the summer (Fig. 3). In the winter three months the Caucasus Mountains and the Urals receive less than 10 per cent of the annual average, while the plains between receive more than 20 per cent. In both seasons the effect of the mountains is therefore to give a more marked extreme, the distribution throughout the seasons in the plain being much more uniform. December is the wettest month of the year in the west of the British Isles as well as in parts of Italy, Sicily and Greece.

Some of the extreme falls are set out in Table V.

TABLE V.—AVERAGE RAINFALL, FALL OF WINTER AS A PERCENTAGE OF THE YEAR.

Country, etc.	Station	Fall of Winter (per cent of year)
(*a*) *large*	*values*	
Malta	Malta	46
Greece	Corfu	43
Italy	Catania	42
Greece	Patras	41
Gibraltar	Gibraltar	41
(*b*) *small*	*values*	
Russia	Ekaterinburg	7
Russia	Vladikavkaz	9
Russia	Pjatigorsk	10
Russia	Kasan	11

During the months December, January and February the Asiatic high pressure system increases in intensity and the high pressure belt stretches to eastern Russia. This is in harmony with the facts that the distribution on the rainfall map for the winter (Fig. 5) is similar to that for the autumn (Fig. 4) in that the values decrease from the west coast to eastern Russia, while the values are smaller in central and eastern Europe on the winter map.

4. AVERAGE MONTHLY RAINFALL IN JANUARY AND JULY

In dealing with the rainfall of the British Isles January is usually chosen as the month in which the proportion of the year's total is greatest in the rainy westerly uplands, illustrating the predominance in that month of rain of the orographical type. There is also a well-marked minimum along the east coast in the districts where orographical rain is least frequent. A complete reversal occurs in July. In this month the usually rainy regions of the west receive a much smaller proportion of the annual amount than the east coast. This is in accord with the weakening of the orographical control in summer. The two maps, Fig. 7 and 8 indicate that the contrast is maintained over Europe. In the Mediterranean region the range is from 15 in January to 1 in July, the range in central districts is typically from 15 in July to 5 in January. It is of interest to compare the percentage falls in each month at typical stations over Europe.

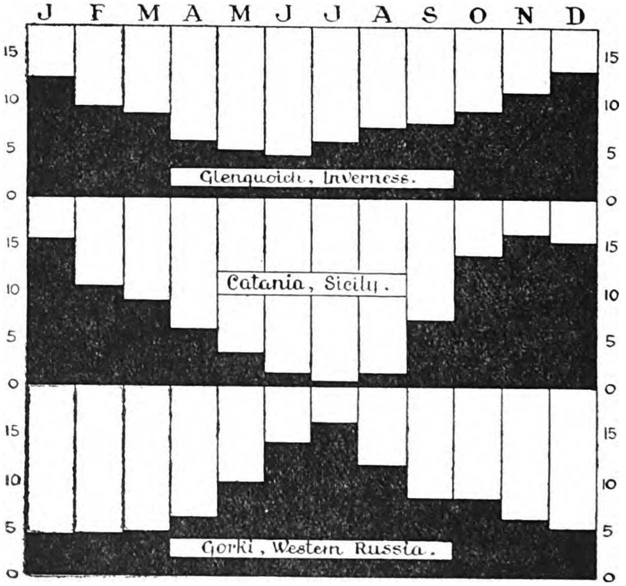

FIG. 6.—Average monthly rainfall as a percentage of that of the year.

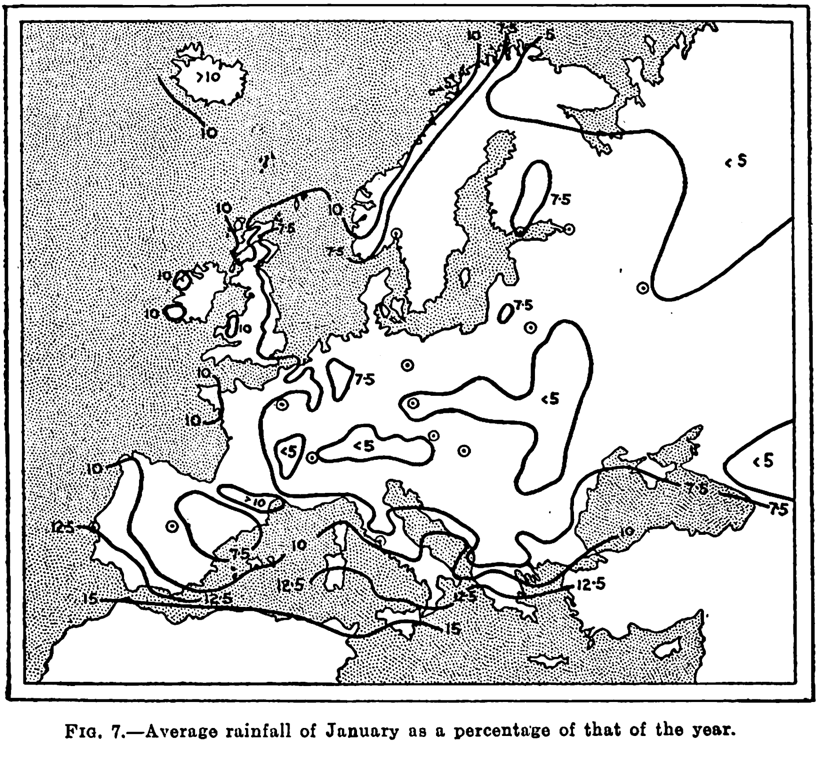
>10
10
7·5
5
<5
>10
12·5
15
12·5

FIG. 7.—Average rainfall of January as a percentage of that of the year.

In Fig. 6 the monthly averages for three stations are expressed as a percentage of the annual averages. At Glenquoich, in the Western Highlands of Scotland, the distribution of the rainfall amongst the months is typical of that experienced over the western half of the British Isles, the north-west of France, Iceland and the west of Norway. This distribution, with a maximum near mid-winter and a minimum in the summer, is typical of those areas where orographical fall is highly developed. The amount of orographical rain in these regions depends on the strength and regularity of the west and south-west winds. They are essentially controlled by the Icelandic low pressure system which is much more intense in winter than in summer.

The distribution in this region is similar to that of the Mediterranean in that both give most rain in winter. There is a marked difference, however, in that while the former has abundant rain all the year round in the latter there is very little during the summer. Catania, in Sicily, has been chosen as representative of the Mediterranean region. It will be seen that the range is much greater than at Glenquoich. At Catania the three months June to August contribute only one thirtieth of the total, while very nearly half the rain of the whole year falls during the three months, November to January.

Gorki, in western Russia, some 300 miles to the west of Moscow, gives a distribution in striking contrast to that at the other two stations. Each of the four months, January, February, March and December receives about one twentieth, while during the three months June to August rather more than two fifths of the total falls.

The falls of January and July, expressed as percentages of the annual average, are shown in Figs. 7 and 8 and as would be expected the latter gives a more complicated distribution. At Melilla, on the north coast of Morocco, as much as 19 per cent occurs in January, while the average for July is 0.0. Some of the largest and smallest values are set out in Table VI. below :—

TABLE VI.—AVERAGE RAINFALL. JANUARY AND JULY AS A PERCENTAGE OF THE YEAR.

Country, etc.	Station	January (per cent of year)	July (per cent of year)
(a) large values for January and small values for July			
Malta	Malta	16	0.2
Sicily	Catania	16	0.5
Gibraltar	Gibraltar	14	0.1
Greece	Patras	13	0.3
Spain	San Fernando	13	0.1
(b) large values for July and small values for January			
Russia	Pinsk	4	18
Russia	Ekaterinburg	2	18
Russia	Nishne Tagilsk	3	17
Russia	Kasan	4	16
Transylvania	Hermannstadt	3	16
Russia	Gorki	5	16

5. The Range of the average monthly Rainfall across Europe[5]

Maps have already been published showing the months of greatest and least average rainfall for all parts of Europe[6], but no indication was given of the actual range between the falls of these extreme months. Hellmann[7] has already pointed out that if the range is expressed as a percentage of the annual average, the greatest ranges occur along the southern fringe of Europe and along the northern and eastern border, the smallest values occurring in the Lower Rhine and in parts of Holland, Belgium, Central France and Great Britain. The relatively small range in the British Isles warrants a separate consideration of that region.[8]

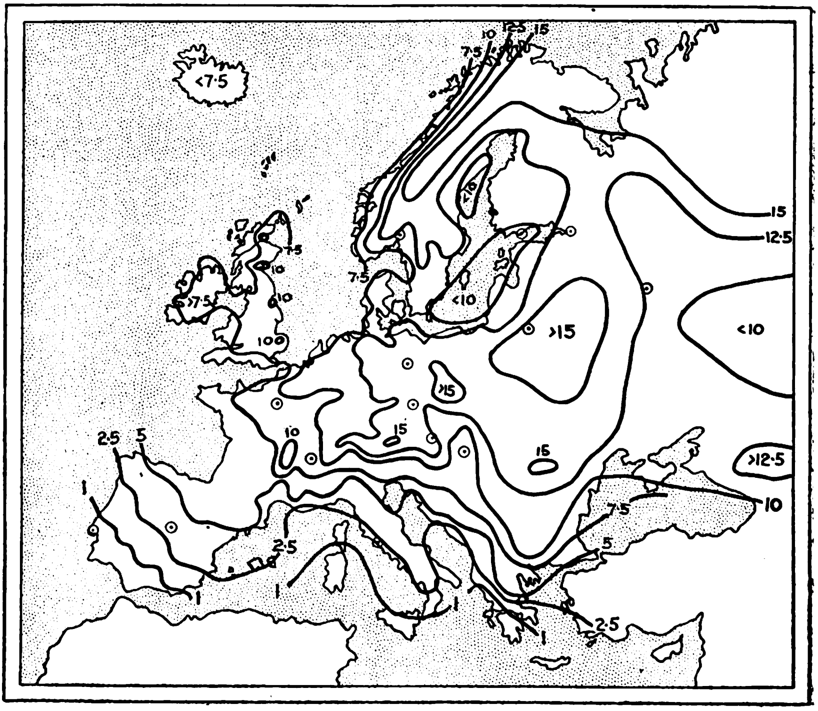

Fig. 8.—Average rainfall of July as a percentage of that of the year.

(*a*) *Range over the British Isles.*—It is shown in Fig. 9 that the averages are most uniform, varying from each other by less than 5 per cent of the annual average, over a large part of central England stretching from Wiltshire to Durham, in London, near the mouth of the River Orwell, to the south of Edinburgh, over part of the extreme north-east of Scotland and over the greater part of the north-eastern half of Ireland. The range increases towards the west of the land masses and exceeds 8 per cent in the Devon-Cornwall peninsula, in South Wales and in the Western Highlands of Scotland. Some of the largest and smallest ranges in each country are set out in Table VII.

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[5] *i.e.*, the difference between the percentage of the average fall in the driest month and in the wettest month regardless of the name of the month.

[6] Months of greatest and of least rainfall in Europe. *Q.J.R. Meteor. Soc.*, **51**, 1925, pp. 275-277.

[7] Untersuchungen über die jahrliche Periode der Niederschläge in Europe. Berlin, 1924, pp. 138-139, by G. Hellmann.

[8] In the paper on " The variability of average monthly rainfall throughout the year " by J. Glasspoole, *Q.J.R. Meteor. Soc.*, **53**, 1927, pp. 127-142, the variability over the British Isles is expressed as a mean deviation from the mean monthly fall.

TABLE VII.—RANGE OF AVERAGE MONTHLY AMOUNTS AS PER CENT OF ANNUAL AVERAGE.

Country	Station	Range (per cent of year)
(*a*) *large values*		
England and Wales		
Devon	Ashburton (Druid House)	9.5
Brecon	Aberdare (Nanthir Reservoir)	8.6
Scotland		
Inverness	Loch Quoich (Glenquoich)	8.8
Ireland		
Kerry	Killarney (District Asylum)	8.6
(*b*) *small values*		
England and Wales		
Warwick	Birmingham (Edgbaston)	4.1
Derby	Mickleover (Clyde House)	4.1
Scotland		
Moray	Grantown-on-Spey	4.0
Ireland		
Down	Seaforde	4.0
Cavan	Belturbet (Cloverhill)	4.1

The large range in Table VII*a* is associated with a large percentage fall in December and a small fall in June. At all these stations there is a gradual transition from December to June, although the subsidiary maximum in August which is well-developed elsewhere, is just discernible. Of these stations, Ashburton and Aberdare experience the largest fall in December and Glenquoich and Fort Augustus the smallest fall in June. The smaller range at stations in the English Lake district and Snowdonia relatively to those in Table VII*a* is occasioned by a larger percentage fall in August and a rather smaller fall in December. This is associated with the geographical position of the English Lake district and Snowdonia with Ireland to the south-west, giving on the average a greater chance of convectional rains than in those districts either further north or south. The rainfall of the Western Highlands of Scotland differs from that of the Devon-Cornwall peninsula in that in the former area the winter fall forms a greater part and that of April to June a smaller part of that of the year. This is doubtless associated with the difference in latitude, and the proximity of the Icelandic low pressure system which is more intense in the winter months. In the west coast of Ireland neither the small fall of April to June in the Western Highlands or the large fall of December in the Devon-Cornwall peninsula is so highly developed and the range is therefore rather smaller than in the former areas.

(*b*) *Range over Europe generally.*—The range over Europe generally is shown in Fig. 9. The range exceeds 12.5 per cent over the northern half of the mountainous region of the Scandinavian Peninsula, over parts of southern and eastern Russia, in Hungary and along a coastal strip of the extreme south from the coast of Portugal to Transcaucasia. To the south the range exceeds 15 per cent over parts of the Urals and Caucasus Mountains, the extreme south of Spain, Corsica and Sardinia, the south of Sicily and along the coasts of the west and south of Greece and Turkey. While the range exceeds 17.5 per cent at Malta and Greece, there are smaller values to the north with less than 7.5 per cent along the west coast of Norway, along the Baltic Sea, and over the Central Plain of Europe. Over the British Isles the range is less than 7.5 per cent everywhere except in the neighbourhood of the English Channel, in the south of Wales, the Western Highlands of Scotland and south-west of Ireland.

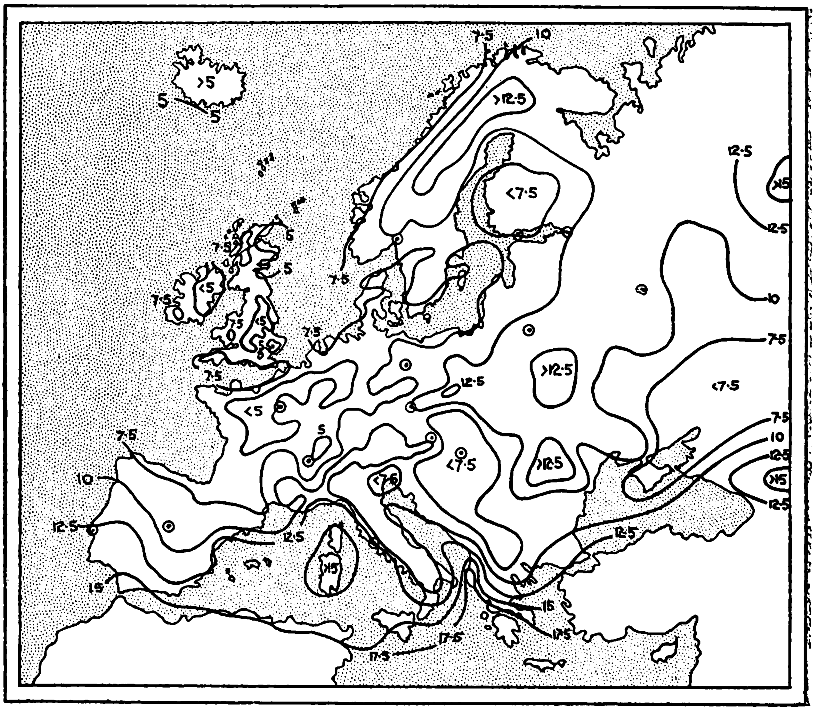

Fig. 9.—Ranges of monthly averages as percentages of the average annual falls.

Reference has already been made to the wide variations in the monthly falls in eastern Russia. The differences have been accounted for by the distribution of the land masses, which give a larger proportion of the rain in the summer—the wet season—than in the adjacent plains. In the dry winter months the proportion falling on the mountains is consequently less than in the plains.

We have seen that in the British Isles, the largest ranges occur along the west coasts exposed to the prevailing wind from the Atlantic, *i.e.*, where the oceanic type is most highly developed. These ranges are much smaller, however, than those occurring in southern and central Europe, where the winter and summer rains respectively form the largest part of the annual rainfall. The southernmost parts of Europe, being characterised by little or no rain in the summer, give the largest values for the range in Europe. The central districts experience some rain all the year round, but the convectional rains of the summer are well marked and these areas give the next largest values.

A comparison of Fig. 9 with Figs. 7 and 8 shows that in most parts of Europe the range (Fig. 9) is given by the difference between the falls of January and July (Figs. 7 and 8). This is more especially the case in the regions of large ranges in southern and central Europe, and some of the stations with the largest ranges are therefore specified in Table VI.

I am indebted to Mr. M. J. Salter, of Mickleton, Glos., for his assistance in the computing work and to Dr. H. R. Mill for his helpful criticism during the preparation of the paper.

DISCUSSION.

Sir RICHARD GREGORY: Dr. Glasspoole's paper is an addition to a series of similar valuable contributions to our Society. It has points of contact with subjects other than pure meteorology, such, for example, as geography, climatology, and agricultural meteorology. If I had seen his chart of the average distribution of rainfall in the summer months, as a percentage of the year, I should have hesitated to go to Norway and Sweden as I have done twice in those months and had wet weather most of the time. The relation between the distribution of the rainfall lines and the coasts and highlands, pointed out by Dr. Glasspoole is very interesting, and the differences between regions of winter rains and the Mediterranean region are most striking.

Dr. C. E. P. BROOKS remarked that while the map of rainfall percentages for winter showed a close resemblance to the map of mean pressure for January, the spring and summer maps showed the influence of thunderstorm frequency remarkably well.

Captain W. N. MCCLEAN said that on such a wide aspect of rainfall as this paper presented he could say little, because his experience was mainly with the rainfall values required in connection with stream flow. Amounts of rainfall were not dealt with in this paper and it would be interesting to have some comparison of amounts, during the summer season, between the coastal and inland areas. It appeared to him that contrasts in temperature of air and land had much to do with rainfall. Over the area in the west of Scotland, of which he had some knowledge, these contrasts might well account for the higher seasonal rainfall of the winter. In the Alps and the mountainous areas of Russia similar contrasts might make the summer season the period of higher rainfall.

Colonel E. GOLD asked whether the uncertainties attached to the measurement of snowfall were likely to result in appreciable errors in the maps reproduced in the paper.

Sir GILBERT WALKER remarked that as the region from Asia Minor to Baluchistan resembled southern Europe in that most of its rainfall occurred in winter, it was natural to suppose that the explanation was largely the same from Spain to India. Did the reader of the paper consider that a comparison of the world pressure charts of January and July provided a complete solution?

Mr. L. C. W. Bonacina considered Dr. Glasspoole's paper a most instructive picture of the seasonal processes in European rainfall. Recently he (Mr. Bonacina) had received a letter asking the reason why Spain had a rainfall which rose to a maximum both in spring and autumn, and he had replied that this appeared to be a passive effect of the removal of dominating high pressure both in winter and summer. In winter the interior of Spain was dominated by local continental high pressure, whilst in summer, in spite of the heat, it was dominated by an extension of the Atlantic high pressure. This last is a peculiarly interesting feature since it keeps a region dry which has otherwise all the factors requisite for a heavy summer rainfall of monsoonal character. When the high pressure released its hold in September, Spain began to get its thunderstorms as noted by Dr. Glasspoole. It is an instructive illustration of the principle that local factors have to compromise with the general factors in the circulation of the atmosphere.

Mr. Bonacina thought that the annual or seasonal course of European rainfall was highly complex and was perhaps more effectively illustrated by taking the individual months than by arbitrarily grouping them into seasons. It is particularly complex in the British Isles where the west European autumn (October) maximum forms, as it were, the substratum, with the oceanic winter (January) maximum in the extreme west and the continental summer (July) maximum or strong secondary maximum in the extreme east.

With regard to Captain McClean's question about temperature contrast he (Mr. Bonacina) considered this was the cause of the west European October maximum which was conspicuous in both England and France. In October the moisture-laden Atlantic winds blow in at a high temperature and react with air supplies over the continent, which in that month is cooling down fast. This west European autumn maximum is less obviously explicable than the central and eastern European summer maximum, or the Mediterranean winter maximum, but the explanation here given at least fits in with the modern principle of "fronts." The winter rains of Persia and northern India referred to by Sir Gilbert Walker were associated with the Mediterranean series of depressions, but they were less heavy than those in the Mediterranean basin.

With regard to Colonel Gold's point about the snowfall in central and eastern Europe it was probable that this very factor renders the rainfall values to some extent uncertain at the higher levels in the British Isles where the fraction of the annual precipitation that falls as snow is considerable and where the snow is usually swept by a fierce gale.

Dr. Glasspoole, in reply, said that he had been led to publish the maps as a result of the interest displayed in them by certain lecturers in geography, who owned that their ideas were not in accord with the facts as shown by the maps.

In reply to Captain McClean he referred to a wall map, showing the average annual rainfall over Europe, which was being published by Messrs. W. & A. K. Johnstons from information supplied by the Meteorological Office. He pointed out that apparently temperature was not the prime cause of the seasonal distribution of rainfall, since in some parts of Europe the winter was the wettest season while in others it was the driest.

In connection with the question of snowfall, Dr. Glasspoole referred to a rain-gauge he had seen in the Swiss Alps at an altitude of about 10,500ft., where the bulk of the precipitation was in the form of snow, and which was accessible only for a few months each year. In such extreme cases it was obvious that the gauge could only be expected to give the roughest idea of the actual precipitation. Fortunately the distribution of the average rainfall amongst the seasons varies little over appreciable areas, and a fairly close approximation could be obtained from the records at the nearest valley stations. Dr. Glasspoole said that before accepting the percentage values he had critically examined them, because of the likelihood of errors due to snow (and over-exposure), and found them reasonably consistent even when the altitudes, and therefore presumably the amount of snow, varied considerably. Apparently therefore any errors due to these causes were not large.

Sir RICHARD GREGORY: We have had an excellent discussion of Dr. Glasspoole's paper and we thank him for bringing so much interesting matter before us. I am sure that many geographers would find the maps and the analysis of the facts represented upon them very instructive.

Cirrus Movement and the Advance of Depressions

During the months January, February and March of 1928 there were 59 nephoscope observations of cloud of cirrus type at one or other of the Meteorological Office stations at Holyhead and Sealand at times when the station concerned could be said to be sufficiently in front of an incoming impression, and yet not too far away for its nephoscope reading to come under survey as a possible means of forecasting the direction and rate of the depression concerned. Some depressions were used more than once, but an interval of at least 8 hours was allowed to elapse before a repeated use.

A careful survey of the subsequent charts was then undertaken with intent to place in each case alongside the nephoscope readings the actual travel of the depression.

Table I. shows the results obtained for direction in the 59 comparisons made.

TABLE I.

Total No. of comparisons made.	Difference in degrees between the cirrus motion and the direction of advance of the depression centre.				
	Nil.	No. of cases difference was—			
		Between 0° and 30°.	Between 30° and 60°.	Between 60° and 90°.	Greater than 90°.
59	7	19	19	13	1

Table II. shows the results obtained for velocity in the 59 comparisons made.

In view of the belief, somewhat commonly held, that secondary depressions as such are more likely to have their progress accurately delineated by the cirrus movement than are primaries, 16 cases of definite

TABLE II.

Cirrus movement.	No. of cases.	Rate of travel of centre of depression centre.		
		No. of cases travel was—		
		Greater than 45 m.p.h.	Between 25 and 45 m.p.h.	Less than 25 m.p.h.
> 100 m.ph.	12	1	8	3
51-100 ,,	28	1	17	10
26-50 ,,	15	0	10	5
< 26 ,,	4	0	4	0

secondary depressions were selected and compared with the nephoscope readings in front of them. Table III. shows the results of that comparison for direction of advance and Table IV. the results for rate of advance.

TABLE III.

Total No. of comparisons made (secondaries only).	Difference in degrees between the cirrus motion and the direction of advance of the centre of the secondary depression.				
	Nil.	No. of cases difference was—			
		Between 0° and 30°.	Between 30° and 60°.	Between 60° and 90°.	Greater than 90°.
16	5	7	3	1	0

TABLE IV.

Cirrus movement.	No. of cases.	Rate of travel of the centre of the secondary depression		
		No. of cases travel was—		
		Greater than 45 m.p.h.	Between 25 and 45 m.p.h.	Less than 25 m p.h.
> 100 m.p.h.	6	1	2	3
51-100 ,,	8	0	5	3
26-50 ,,	1	0	0	1
< 26 ,,	1	0	1	0

It will doubtless be appreciated that the nature of the inquiry made it a somewhat difficult one to carry out in detail. The following results, however, appear to emerge:—

(*a*) The cirrus direction may be taken as a fair—but only a fair—indication of the direction of advance of the depression, but there are many exceptions. The concurrence is far better if secondaries alone be considered.

(*b*) The cirrus velocity appears to have little relation to the velocity of progress of the depression centre whether the depressions be primaries or secondaries.

W. H. PICK.
D. F. BOWERING.

DISCUSSION OF MEMOIRS

G. C. SIMPSON, C.B., F.R.S., ON SOME STUDIES IN TERRESTRIAL RADIATION

[Vol. 2, No. 16. Published March 1928—Read October 17, 1928.]

SUMMARY.

It is assumed that water vapour is the only constituent of the atmosphere which absorbs and emits long wave radiation. From the results of upper air observations approximate values of the temperature and water content of the atmosphere at all heights and in all latitudes are adopted. Knowing the amount of water vapour and the temperature, it is possible to calculate the outgoing radiation if the absorption coefficient of water vapour is known. From consideration of the temperature of the upper stratosphere it is found that one millimetre of precipitable water in vapour form absorbs 30 per cent of the incident long wave radiation. With this value for the absorption coefficient the total outgoing radiation is calculated for each latitude from the equator to the pole, and it is found that over three-quarters of the earth's surface—from the equator to latitude 50°—the outgoing radiation is uniform and independent of the temperature of the surface. This result is due to the fact that it is only the layers of the atmosphere whose temperature lies between 220d and 286d which contribute to the outgoing radiation. As these layers are well within the troposphere between the equator and latitude 50°, the outgoing radiation is uniform from 50°S to 50°N. At higher latitudes the radiation falls off slightly, and at the pole itself it is 20 per cent below its value at the equator.

As the outgoing radiation is practically independent of the temperature of the surface, the problem arises as to how the temperature of the atmosphere readjusts itself to changes in solar radiation. This problem is considered in detail, but no solution is found.

G. C. SIMPSON, C.B., F.R.S., ON FURTHER STUDIES IN TERRESTRIAL RADIATION

[Vol. 3, No. 21. Published July 1928—Read October 17, 1928.]

SUMMARY.

By using the observed temperatures of the earth's surface and of the stratosphere, and observed values for the absorption coefficients for water vapour and carbon dioxide, approximate values have been obtained for the outgoing radiation from the earth and its atmosphere, and the laws governing nocturnal radiation have been indicated. Values have been found for the horizontal transfer of heat across the circles of latitude which is necessary to obtain radiative equilibrium of the atmosphere as a whole. The consequences of changes in the intensity of solar

radiation have been investigated, and the conclusions drawn that change in cloud amount would be the chief agency by which radiative equilibrium would be restored. An increase in solar radiation would result in increased cloud and precipitation, while a decrease in solar energy would lead to less cloud and less precipitation. The possibility of increased solar activity leading to an " ice age " is discussed.

DISCUSSION of both Memoirs, taken together.

Dr. L. F. RICHARDSON said that the atmosphere resembled London for in both there were always far more things going on than anyone could properly attend to. He who showed what could harmlessly be neglected had done a useful work. Dr. Simpson had shown that for radiation. By a set of bold simple approximations Dr. Simpson had obtained a number of brilliant agreements with observation. The author was to be congratulated on having produced, and the Society on having published, this excellent second *Memoir*. Nevertheless we might look critically at certain details. Was it not possible that some absorption band which was significant in the kilometres of the atmosphere might have escaped detection in the laboratory where tubes could only be a few metres long? Angström's observations on Mount Whitney indicated that even dry air absorbed.

Again, according to classical electrodynamics, as Lindemann had remarked, wherever there was absorption there must also be scattering. [Added later: The new quantum theories of Schrœdinger and Dirac seem to lead to the same conclusion. See "The New Quantum Mechanics," by G. Birtwistle (Camb. Press, 1928) Ch. XXII., Ch. XXX]. Lastly there was the obliquity of the rays. He hoped that someone would examine the question further, using the more rigorous analysis of Gold and of L. V. King. If so, Dr. Simpson's paper would be a good starting point. [Added later: Obliquity can conveniently be treated by working separately with three zones and six zones and making a "deferred approach to the limit." *Phil. Trans A.*, **226**, 1927, p. 299.]

Mr. L. C. W. BONACINA thought that, in relation to the part which Dr. Simpson very forcibly shows can be attributed to clouds in maintaining radiative equilibrium, an assumption, bearing vitally upon the argument, is made that is at least debatable. This is the assumption that more cloud would develop over the whole globe in consequence of increased activity of the general circulation in response to increased radiation from the sun. Now it is important to remember that processes in the earth's atmosphere are complementary, and that any increase in the intensity of the rain and cloud-producing areas of the globe should necessitate also an increase in the drought-producing areas. Arguing from general principles it seemed to him (Mr. Bonacina) that any increase in the activity of the general circulation following upon increased solar activity would have the following effect:—

Cloudy Equatorial belts:	evaporation	+,	condensation	+.
Clear Trade belts:	,,	+,	,,	−.
Cloudy Westerly belts:	,,	−,	,,	+.
Clear Polar belts:	,,	−,	,,	−.

The plus and minus signs simply symbolize increase or decrease with reference to standard conditions. There is a suggestive symmetry in this scheme that does not accord with the idea of a general increase of cloud in all circulation belts. If the scheme is correct it would mean that Dr. Simpson would have to find the proper excess of cloud entirely in the cloudy belts, the excess in those belts more than balancing the deficiency in the clear belts.

Colonel Gold referred to the advance in our knowledge of radiation which had occurred in the past 20 years and expressed the opinion that it would not have been practicable to have a discussion such as they were having that evening 20 years ago. He thought that one of the most valuable features of the paper consisted in the tables, such as Table I. Such a table simplified greatly the application of theoretical results to practical problems. When one had to calculate the values which one desired to use from the fundamental formula

$$\frac{C}{\lambda^5\,(e^{c/\lambda T}-1)}$$

it made work on radiation a very arduous task.

The fact that the atmosphere was not a grey body was recognised by those who worked on atmospheric radiation many years ago. He himself had taken as one basis for computation that 25 per cent of black-body radiation at terrestrial temperatures was transmitted freely through the atmosphere and he had indicated that the variation in the height of the stratosphere with latitude could not exist if the atmosphere were a grey body (*London; Rep. Brit. Ass.*, 1910).

In connection with this it was an interesting fact that the higher the absorbing power of the atmosphere the lower the temperature and the greater the height at which the stratosphere begins. (*Proc. R. Soc.*, 1909, pp. 64-66; *London, Rep. Brit. Ass.*, 1910, p. 546).

There was another point which he thought needed consideration—the absorbing power of a gas depended not only on the total amount of gas in the path of a beam of radiation, but also on the density of the gas. Most of the experiments in which the absorbing coefficients had been found were made with gases at atmospheric pressure (about 1,000mb.). In the case of water vapour the experiments have usually been made on steam. The absorption, and therefore the radiation, of water vapour in a state so tenuous as the water vapour in the stratosphere might be very different in magnitude from the absorption of an equal quantity of water vapour whose density was 30,000 times as great. Langley's observations, taken in conjunction with those of Paschen and Rubens and Aschkinass supported this view. [What appears to be a continuous band of absorption in the case of steam may in fact consist of a series of broadened lines or strips, which would have between them lines or strips of little or no absorption in the more tenuous vapour. Actually most of the experimental results do indicate relatively sharp maxima in the absorption curves, which would accord with this view. Moreover it is by no means certain that the experimental results on the absorption in the region of longer wave lengths of 10 to 30 μ are free from considerable error; the difficulties of the experiments and the fact that radiation from the surroundings may be comparable in magnitude with the radiation under measurement would make detailed accuracy in all points most unlikely. If a source of high temperature is used for the emitted radiation, then it is difficult to exclude the effect, possibly indirect, of radiation of short wave lengths (which may be 10,000 times the intensity of the radiation under measurement); if a source of low temperature is used, then the radiation under measurement is of the same order of magnitude as the radiation of the same wave length from the surroundings of the apparatus, and these surroundings cannot be kept at an invariable temperature]. It might be argued that the agreement of the results of the computations with the observed facts or with the non-reflected balance of solar radiation was in itself sufficient justification for the assumption that there was no material difference between the absorption of water vapour in the stratosphere and the absorption of water vapour under a vapour pressure of 1,000mb. But these computations were all of an approximate character and it might be that the results agreed because errors of different signs cancelled out. For example, no computation of radiation conditions in an atmosphere in which temperature decreases with height could be entirely accurate, if it were assumed that the absorption and emission of radiation by any layer followed the same law. For example, the radiation of any wave length arriving in a vertical direction from below would on the whole arise from layers of higher temperature than if it came in an inclined direction. Consequently a smaller proportion of the total radiation would be absorbed in passing through the layer than if it were black-body radiation.

Clearly the paper was not, and did not aim at being, a final solution of radiation in the atmosphere; it did, none the less, constitute a valuable addition to the literature on the subject and it was written in a way in which it could be readily followed by any professional meteorologist even if he had no very advanced mathematical knowledge.

[*Note added subsequently*: He was struck by the close agreement of the absorption coefficients given in Fig. 1, page 4, with the values deduced from observations of Rubens and Aschkinass on page 49 of his paper (*Proc. R. Soc.*, **82,** 1909). It is an extraordinary coincidence that Rubens and Aschkinass should have made their experiments on an amount of water vapour very nearly exactly equal to the amount of water vapour in the stratosphere. Dr. Simpson states that the atmosphere is perfectly transparent to radiation between $8\frac{1}{2}\mu$ and 11μ, but he does not give his reasons for excluding the very strong absorption of ozone between 9 and 10μ found by Ångström, Ladenberg and Lehmann and Eva von Bahr. While the absorption of ozone may be of no great importance for the lower atmosphere he had always assumed that it was of material consequence in a case of radiation from or through the stratosphere.

In connection with the reference to himself on page 2 he might mention that he first stated his reasons for considering that the atmosphere at the base of the stratosphere must be saturated with water vapour in the report by Dr. Harwood and himself to the British Association at Winnipeg (*London, Rep. Brit. Ass.*, 1909, p. 108.]

Mr. L. H. G. Dines said that he was chiefly interested in the question of nocturnal radiation. The observations made at Benson which have been summarised in *Memoirs of the R. Meteor. Soc.*, No. 11, and are referred to by Dr. Simpson in Table VI. of *Memoir* No. 21, provide a means of testing the correctness of the assumptions made by him in regard to the extent to which wave lengths between 7 and 14μ are absorbed by the atmosphere. The observations consisted of values of long wave radiation received from various elevations ranging between the vertical and an elevation of $7\frac{1}{2}°$. In the latter case the path of the entering ray through any definite horizontal layer is about eight times the length of the vertical ray, so that if a certain wave length suffers absorption of anything over, say, 10 per cent in the case of the vertical ray very little indeed will get through in the case of that at an elevation of 7½°.

In Fig. 5 of *Memoir* No. 21 the bounding curve refers to a temperature of 280a, and in Table VI. it will be seen that the mean temperature of the surface black body at Benson in March was also 280, hence in discussing the observations made in March we may use Fig. 5 without modification. Now referring to Table I. of *Memoir* No. 11, it will be found that the ratio between the radiation in March received from the zenith and from the surface black body was 65 per cent, and between that from an elevation of 7½° and the black body it was 91 per cent. The point is that on Dr. Simpson's assumptions it is difficult to arrive at a value as great as 91 per cent. Referring to Fig. 5 we see that at the elevation 7½° the radiation received between wave lengths 14 and 50μ must have been represented by the area HCH on the right of the diagram; between 14 and 11μ it must have been nearly, but not quite, equal to the area AKCH. Between 11 and 8½μ is the debatable region; between 8½ and 7μ the radiation received must have been nearly equal to the area GFJD, while below 7μ, save for a very small correction, we may take the whole area below the curve LF. On adding up these areas by a planimeter it appears that even if we fill up the whole area between 7 and 8½ and 11 and 14 we cannot get more than about 83 per cent. The only way in which the area can be increased is by filling up part of the region between 8½ and 11, and as it is impossible to conceive of the whole of the regions on each side of it being full it will be necessary to fill up about 2/3 of it before a reasonable curve can be drawn and at the same time the ratio of 91 per cent be arrived at.

Such a large amount of radiation between 8½ and 11μ in the case of the ray at elevation 7½° implies that an appreciable amount, say 9 per cent, of the vertical ray between these wave lengths must be absorbed by the atmosphere. It is to be observed that since the temperature of the air decreases with height this figure is too small rather than too large.

A reason for this absorption may be found in the presence of material particles suspended in the air, but this does not alter the conclusion that the atmosphere as it exists, by reason of dust or otherwise, absorbs an appreciable percentage of radiation between 8½ and 11μ. It can be argued that the air at Benson is on the average more contaminated by material particles than the air over the globe as a whole, and in such case the results obtained there do not apply to Dr. Simpson's conclusions as regards the globe as a whole.

Dr. L. F. RICHARDSON said that, knowing the apparatus, he found Mr. L. H. G. Dines's argument about imperfect transparency convincing.

During the course of the discussion Dr. SIMPSON made the following replies, and he has added further replies to the addenda.

With regard to Dr. Richardson's suggestion that there may be some absorption band due to oxygen or nitrogen in the long-wave region which had not been taken into account in the paper and might be significant when kilometres of atmosphere were involved, it should be pointed out that the opinion of Burmeister, quoted in the paper, was based on theoretical considerations and not on direct experimental observations. These theoretical considerations clearly show that none of the elementary gases of the atmosphere have absorption bands of wave lengths greater than 1μ. This theoretical reasoning is supported so far as the observations go, and it makes it very probable that Burmeister's calculation is correct and absolutely certain that there can be no absorption bands of sufficient intensity to affect the general reasoning of the paper.

Angström's observations on Mount Whitney do not indicate that "even dry air absorbed." What Ångström showed was that his observations on Mount Whitney indicated considerable radiation of long waves from the atmosphere above. There can now be no doubt that this radiation comes from the water vapour in the upper atmosphere, and in the paper I remark that Ångström's observations agree with the amount of radiation from the stratosphere which the theory in the paper indicates. I also should be glad if somebody would "examine the question further, using the more rigorous analyses of Gold and L. V. King," but as my method was developed because these more rigorous analyses are so difficult as to be almost impracticable, I see no reason why we should wait for this fuller investigation before accepting the conclusions of my paper.

I quite agree with Colonel Gold's remarks that there is a difference between the absorption of water vapour with low density as compared with water vapour at high density, and as a matter of fact I used this difference in my paper to explain why Hettner found considerable absorption between $8\frac{1}{2}\mu$ and 11μ, while Abbot and Aldrich found practically no absorption in this region. At the same time I do not think that this effect, the magnitude of which is now fairly well known, can necessitate any material change in the method of the paper. It might shift to some small extent the wave lengths adopted as the limits of the regions of total absorption by the stratosphere, but it cannot affect materially the absorption in the stratosphere set out in my Fig. 2. Quite appreciable changes in the wave lengths which limit the five regions which I consider can be made without altering the character of the results. As stated by Colonel Gold my method is admittedly an approximate method; the only justification for which is that it does give a balance between incoming and outgoing radiation accurate to a few per cent. Ultimately this is the only justification for this or any other approximate method.

In the note which he subsequently added Colonel Gold raises a question which I purposely did not consider in my paper, namely, the effect of the ozone in the upper regions of the atmosphere. There are several reasons which confirm me in my belief that the radiation from this upper layer may be neglected. One, however, must suffice here. The ozone layer can only radiate as much energy as it absorbs from the incoming and outgoing radiation. Now we know very approximately the extent and magnitude of the ozone bands and although I have not made an actual numerical calculation, it will be generally agreed that the small amount of ozone in the upper atmosphere can only absorb a very small fraction of the total incoming and outgoing radiation, probably at the most one or two per cent. As the amount absorbed is radiated in both directions only half of it can enter into our circulation, and I feel justified in leaving this small amount of radiation out of account.

I find considerable difficulty in understanding the point of Mr. Bonacina's criticisms. I distinctly said in my paper that the "increase in cloud amount would naturally occur chiefly in the three main cloud belts, one over central regions and two in high latitudes. In between these belts the skies would probably remain relatively clear." The only difference between us so far as I can see is that Mr. Bonacina wishes to state definitely that in four regions, namely, the two trade belts and the two polar belts, the cloud amount would actually decrease. I am not prepared to be as dogmatic as that. I think that all that we can say in the present conditions is that in these belts the skies would probably remain relatively clear. In any case there could be little doubt that the total cloud amount for the world as a whole would definitely increase with an increased general circulation, and that is all that I was out to demonstrate.

The remarks made by Mr. L. H. G. Dines are based on a misapprehension. My Fig. 5 was not supposed to represent the radiation through an indefinitely long column of air near the ground. It represents the energy which falls on a flat surface from all regions of the sky. In many conditions of the atmosphere the flux of radiation in a horizontal direction near the ground must be very nearly 100 per cent of the radiation from a black body at the temperature of the air. I am therefore not surprised that he has found that the radiation received from rays at an elevation of $7\frac{1}{2}°$ is 91 per cent of black-body radiation. This high radiation from rays near the surface is not due entirely to the length of the column traversed, but is also due to the fact that in this region the atmosphere is heavily charged with particles, partly solid and partly liquid, which radiate as true black bodies. I would refer Mr. Dines to the paper by Fowle referred to on page 3 of my paper, in which he shows, as stated by me, that he and Abbot could "detect no certain absorption by the aqueous vapour in the atmosphere from wave length 9μ to 12μ even when there was vapour in the path equivalent to 2cm. of precipitable water." This is a wider region of wave length than that which I take for a transparent atmosphere, namely, between wave lengths $8\frac{1}{2}\mu$ and 11μ. If Mr. Dines's contention that there is appreciable radiation in this clear band were correct, then the Benson observations which I have plotted on Fig. 6 should fall very much nearer the minimum line than any of them do in reality, for this line can only be reached when the atmosphere is acting as a full radiator at the temperature of the apparatus in all wave lengths except the narrow clear band between $8\frac{1}{2}\mu$ and 11μ. If there were appreciable radiation in this band, the points would lie below the minimum line.

Meteorology at the University of Salonika

A Chair of Meteorology and Climatology has been created at the University of Salonika and in connection with it a Meteorological and Climatological Institute has been formed. Dr. E. G. Mariolopoulos, F.R.Met.Soc., has been nominated to the Chair and the direction of the Institute will also be in his hands. Dr. Mariolopoulos was a student of the School of Meteorology in the Imperial College of Science under Sir Napier Shaw. Prior to taking up his new appointment Dr. Mariolopoulos was head of the Meteorological Section of the National Observatory at Athens; he has published several works on the climate of Greece.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY

October 17, 1928

An *informal meeting* was held in the Fellows' Room on this date in order to discuss the two *Memoirs* by Dr. G. C. Simpson, Nos. 16 and 21. The summaries of these Memoirs and the discussion will be found on pp. 73 to 79.

November 21, 1928

At the *Ordinary Meeting* the following candidates were balloted for and elected Fellows of the Society:—

Balebeil Anant Acharya, M.I.Struct.E., Public Works Department, Fort, Bombay;
Cicely Mary Botley, 17, Holmesdale Gardens, Hastings;
Alan John Brown, Wetherdene, Thatcham, Berks.;
Santosh Kumar Das, c/o Messrs. Thos. Cook & Son, Ltd., Berkeley Street, W.1;
Mariano Doporto, Director del Observatorio de Igueldo, San Sebastian, Spain;
James Reuben Gibbs, Deer Park Manor, 80, St. Clair W., Toronto;
Thomas Ingledew Grimer, M.R.San.Inst., 2, Southwood Avenue, Tunbridge Wells;
Joseph Eric Hewitt, Flt.-Lieut., R.A.A.F., St. Kilda Road, S.C.I., Melbourne, Australia;
Graham S. P. Heywood, 4, The Leaze, Burford, Oxon;
Shyam Saran Lal, c/o Messrs. Thos. Cook & Son, Ltd., Berkeley Street, W.1;
Robert Conacher Malcolm, Survey of India, 15, Wood Street, Calcutta; and
Amba Prasad Mathur, c/o Messrs. Thos. Cook & Son, Ltd., Berkeley Street, W.1.

Messrs. Ball, Baker, Ash & Co., Chartered Accountants, were appointed auditors of the Society's accounts for 1928.

December 19, 1928

At the *Ordinary Meeting* the following candidates were balloted for and elected Fellows of the Society:—

Alan Francis Crossley, St. Mary's Abbey, Cardington Road, Bedford; and
Francis William John Skutil, 21, Winterhey Gardens, Wallasey, Cheshire.

CORRESPONDENCE AND NOTES

International Congress of Oceanography

An International Congress of Oceanography, Marine Hydrography, and Continental Hydrology will be held at Seville from May 1 to 6, 1929. Delegates of governments, corporations, scientific institutions, and international commissions will take part. The Congress will be divided into two sections, one of oceanography and marine hydrography, and the other of continental hydrology. The programme of the Congress is not yet published. Any one interested should apply to M. Rafael de Buen, Instituto Español de Oceanografia, Alcala, 31, Madrid.

Ground horizontal Visibility at Valentia and the type of Air prevailing

The object of the present note was to determine whether, even at a place like Valentia in Ireland where the atmosphere is comparatively free from vitiation due to smoke and the like, the degree of horizontal visibility prevailing can be shown to be decisively dependent on the type of air present, the type being based on the origin of the air and its subsequent travel.

The Geophysical Institute at Bergen, Norway, issues daily synoptic charts of Europe and the Eastern Atlantic based upon observations at 7h. G.M.T. These charts have the type of the air streams marked upon them in accordance with the Bjerknes ideas of map analysis. Examination of the charts therefore enables the horizontal visibility at Valentia at 7h. G.M.T. to be brought into relationship with the type of air prevailing. The results of the comparison over the period 1st April, 1927 to 31st March, 1928, are shown in the table below. Cases when rain was actually falling at Valentia are omitted as it was deemed that the vitiation brought about by falling rain prevented any just use of the visibilities reported. The visibility numbers employed in the table are those of the usual scale, universally employed internationally: 9 signifying that an object at 31 miles can be seen, 8 that an object at 12½ miles can be seen but not one at 31 miles, 7 that an object at 6¼ miles can be seen but not one at 12½ miles, 6 that an object at 2½ miles can be seen but not one at 6¼ miles, 5 that an object at 1¼ miles can be seen but not one at 2½ miles, and so on.

Type of air at Valentia as indicated on the Bergen Chart.	April to September.				October to March.			
	No. of cases visibility was—				No. of cases visibility was—			
	9	8	7	6	9	8	7	6
Genuine polar	7	1	0	1	1	13	1	0
Maritime polar	25	57	11	3	0	59	9	0
Sinking polar	2	1	0	0	0	1	0	0
Sinking maritime polar	0	1	0	0	0	0	1	0
Returning polar	5	3	1	0	0	0	0	0
Returning maritime polar	1	1	0	0	0	3	1	0
Direct maritime polar	1	1	0	0	0	0	0	0
Former maritime polar	0	0	0	0	0	3	1	
Maritime cold	0	2	1	0	0	1	0	0
Former maritime cold	0	1	0	0	0	0	0	0
Continental air	0	0	1	0	0	8	3	0
Warm and quasi-warm	1	2	0	0	0	4	0	0
Tropical air	4	17	3	1	0	6	5	1

(There was only 1 case of a visibility less than 6 occurring and that was one of 5 which occurred with tropical air in winter.)

A careful scrutiny of the table seems to suggest that no particular degree of visibility can be associated invariably with any particular type of air: a result that suggests that local history is of more importance than remote. Even with tropical air 21 out of 25 cases in summer gave visibilities of 12½ miles.

In connection with the present note similar results obtained by one of us and Mr. J. S. Farquharson* for Cranwell, Lincolnshire, are of interest in view of the fact that the lack of marked correlation previously obtained at an inland station, possibly smoke-affected, is now paralleled at a sea station not smoke-affected.

W. H. Pick.
D. E. Davies.

3rd December, 1928.

Conditions in the Upper Air on October 2nd, 1928

During the day of October 2nd, 1928, aeroplane ascents at Duxford (Cambridgeshire) and Utrecht (Holland) revealed very marked temperature changes in the upper air over eastern England and the southern North Sea which it may be of interest to place on record. In the course of about 24 hours, the ascents showed fluctuations in the temperatures at 800mb. (6,500 feet) and above of between 12°F. and 16°F.

At the time pressure changes were small in this area. At 18h., October 1st, a large anticyclone stretched from off south-west Iceland to the west of Ireland with an extension across northern France. To the north-east an extended belt of low pressure prevailed from northern Greenland to the Black Sea. In this belt a vigorous disturbance was located west of Nordoyan off the Norwegian coast (65°N., 8°E.) which moved quickly south-south-east and reached a position over the Cattegat by 7h. October 2nd. Subsequently the disturbance began to fill up and its rapid motion gave place to a slower south-easterly drift. Behind it the anticyclone drifted slowly eastwards; at 18h. on October 2nd it was centred over England and Ireland and by 7h. on the following day the centre was over the southern North Sea and western Germany.

There was associated with this secondary depression, an occlusion, which at 18h. October 1st ran southwards over south-western Norway, turned south-westwards across the North Sea and could be identified near Eskdalemuir by the slight drizzle there during the evening. The occlusion moved southwards with the depression and gave rain in southern Norway, Denmark and along the coast of the Netherlands and western Germany. The passage of the occlusion over England was not, however, associated with rain, apart from some slight continuous rain in the Liverpool-Chester area, Chester reporting 0.2mm. and Liverpool a "trace." The autographic records from Felixstowe show a rather slow but marked veer of the wind from west to west-north-west at 4h. 15m. October 2nd, while the wind speed fell off for a time, so that we have definite evidence of the passing of the occlusion. By 7h. of the morning of the 2nd it was easily traced from Hamburg to Utrecht and along the coast of Flanders. Thus the speed of the occlusion was rather less than 30 m.p.h., so that it must have passed Duxford at 3h. on the same morning.

The 7h. chart revealed a very feeble front over eastern England, which, although more diffuse at the surface, gave slight drizzle at Birmingham at 6h. 30m., a slight shower at Gorleston about 11h., and further slight drizzle at Leafield and Worthy Down just before 13h. Again, however, it was only on the autographic records from Felixstowe that the passage of the front was clearly shown at 15h. when the wind veered from west to a point east of north, the speed increased suddenly before the onset of light variable winds occasioned by the eastward drift of the anticyclone, and the temperature fell 2°F. From the available data this discontinuity appeared to have a speed of only 13 m.p.h. and would therefore have passed Duxford between 13h. and 13h. 30m. Behind it a slow but definite rise of the barometer set in. In the map for 7h. October 2nd, which is reproduced in Fig. 1, the positions of the two fronts are shown. The wind speeds at 2,000 feet throughout the period as shown by the pilot balloon ascents are in good agreement with these estimates of the frontal speeds.

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* W. H. Pick and J. S. Farquharson. Ground day visibility at Cranwell, Lincolnshire, in relation to the type of air. *Q. J. R. Meteor. Soc.*, **53**, p. 293.

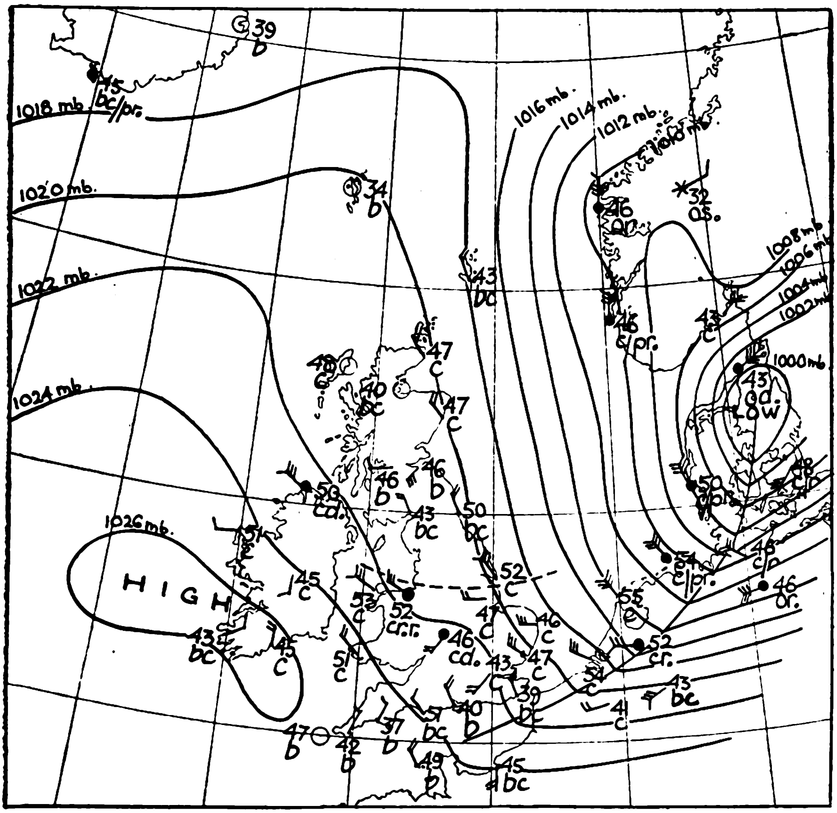

FIG. 1.—7h. Tuesday, 2nd October, 1928.

We are now in a position to examine the data of upper air temperatures which are set out in the accompanying table, and derived from three ascents at Duxford between 8h. 30m. October 2nd and 9h. 45m. October 3rd, and three ascents at Utrecht at 7h. on the consecutive days October 1-3. As we have seen the occlusion was near Utrecht at 7h. October 2nd at the time when the second of the three ascents at Utrecht was made. The warm air in the occlusion was here shown above an inversion of 3°.6F. at 788mb. (6,800 feet) the temperature having risen since the previous day by 15°F. (from 17°F. to 32°F.) at 747mb. (8,200 feet) and by 17°F. at 617mb. (13,120 feet). Similar conditions must be presumed to have prevailed at Duxford during the previous night; yet the ascent at 8h. 30m. revealed that the air at the higher levels was considerably colder than during the previous afternoon, the temperature at 750mb. (8,150 feet) and 700mb. (9,940 feet) being 6°F. lower, due to the influx of the cold air in the rear of the occlusion. Up to the height corresponding with 650mb. (11,800 feet), the maximum level reached in the ascent, there is no indication of warm air above. The aeroplane at Duxford thus failed to reach the inversion under the warm air, and using this fact in conjunction with the information from Utrecht, we infer that the surface of transition between the cold air in the rear and the warm air in the occlusion must have made a slope. with the horizontal of at least 1 in 125.

VALUES OF UPPER AIR TEMPERATURES.

Duxford. 8h. 30m. 2/10'28.			Duxford. 14h. 30m. 2/10/28.			Duxford. 9h. 45m. 3/10/28.		
Pressure.	Temp.	Rel. Hum.	Pressure.	Temp.	Rel. Hum.	Pressure.	Temp.	Rel. Hum.
mb.	°F.	%	mb.	°F.	%	mb.	°F.	%
1018	49	79	1020	55	83	1023	52	77
978	45	78	983	50	77	987	48,5	60
950	44	82	950	45.5	89	950	42.5	67
900	40	77	900	40	81	900	36.5	79
850	32	90	850	32.5	95	850	38,5	34
800	25.5	80	800	38	42	800	36	19
750	19.5	65	750	35	54	750	32.5	?
700	16.5	59	700	29.5	62	700	28	53
650	13.5	64	650	22	69	650	22	46

Utrecht. 7h. 1/10/28.			Utrecht. 7h. 2/10/28.			Utrecht. 7h. 3/10'28.		
Pressure.	Temp.	Rel. Hum.	Pressure.	Temp.	Rel. Hum.	Pressure.	Temp.	Rel. Hum.
mb.	°F.	%	mb.	°F.	%	mb.	°F.	%
991	48	85	992	50	92	1003	52	55
955	45	85	967	46	92	978	46	55
897	37	92	900	41	92	909	39	75
843	30	92	847	34	85	856	30	92
792	25	65	795	29	85	804	36	15
743	17	45	747	32	15	755	34	15
696	14	45	701	28	15	709	30	15
611	1	35	617	18	25	624	19	15

The second ascent at Duxford at 14h. 30m. showed a complete change in temperature above 830mb. (5,650 feet) with an inversion of 9°F. between 830mb. and 780mb. (5,650 to 7,200 feet). At 750mb. (8,300 feet) temperature had risen from 19°.5F. to 35°F. and even at 650mb. (12,100 feet) the increase was as much as 8°.5F. On the following morning (October 3rd) the ascent at Utrecht, the last of the series given in the table, while not greatly differing from that 24 hours before, revealed that in the upper air the conditions were now almost exactly the same as those at Duxford on the previous afternoon except that the base of the inversion of 7°F. had descended to 847mb. (5,200 feet) and the layer was rather less deep. By 9h. 45m. the base of the inversion was located at Duxford at 900mb. (3,550 feet) and its magnitude was reduced to 2°F., temperature having changed little at the higher levels.

Since we know the speeds of the air masses involved we can utilise the series of ascents at the two stations to construct a diagram showing the sequence of changes in the upper air over the area concerned. We shall assume that an air mass over Duxford at any instant, subsequently arrived at Utrecht without having undergone any material change, an assumption which seems reasonable in this case, since the fronts moved south-eastwards. We will also assume that, for the purposes of the diagram, the air masses involved can be represented as advancing in a continuous line from north-west to south-east. This has been done in the accompanying diagram (Fig. 2) which may be regarded as a representation of the instantaneous conditions over a vertical section normal to the first trough. In constructing the diagram the reference point accepted was the position occupied by Duxford relative to the fronts at 7h. October 2nd. This is indicated by the point A on the diagram, and for this reference point the horizontal mileage scale is accurate. It must be pointed out, however, that the fact that the two fronts were travelling at different speeds caused the mileage scale to change with time without affecting the sequence of changes. The full lines in the diagram are isopleths of potential temperature indicating a range from 50°F. near the surface to 85°F. in the highest levels reached, at intervals of 5°F. The gradient of potential temperature increases with decrease in

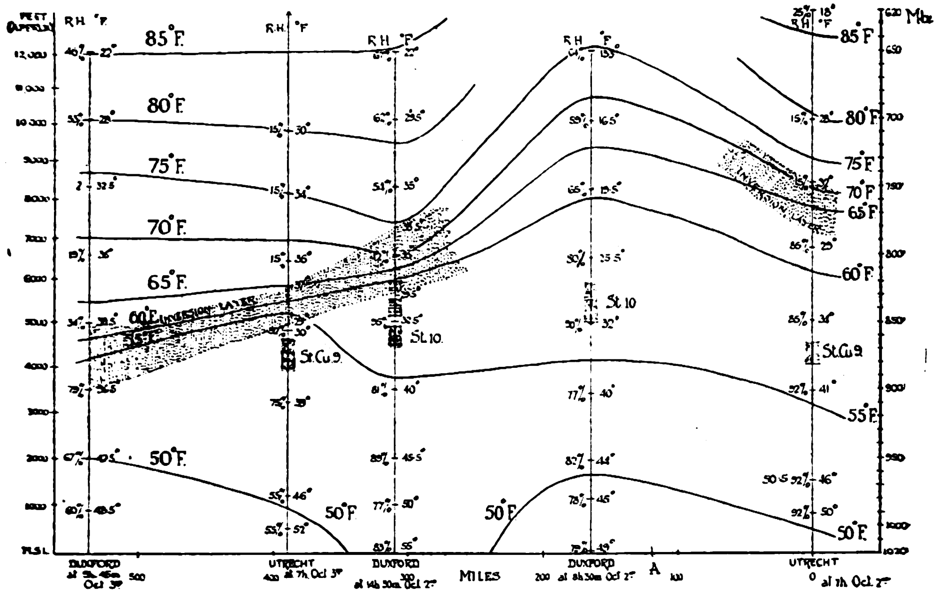

FIG. 2.—Diagram showing the sequence of changes in the upper air conditions on 2nd October, 1928.

Isopleths of potential temperature ———

Cloud layers ▤

Inversion layers ░

The vertical scales show pressures in millibars and approximate heights in feet. The horizontal scale is a mileage scale. Values of temperature and relative humidity at the various pressures are also shown.

the lapse rate until, in the case of an inversion, the gradient becomes very steep and the isopleths of potential temperature are crowded together. This is clearly shown in the diagram in which the inversion layers are indicated as stipled areas. The details of the five ascents on which the figure is based are included and show the magnitude of the changes. Cloud information is shown in detail for Duxford, but for Utrecht it was available only in the coded wireless messages and is consequently limited and only approximate.

Some points of interest emerge from consideration of the warm air masses in the upper layers. The complete data reveal that the occlusion was not a typical example with warm, rain-producing air in the higher layers; instead, the air in the upper layers, although warm, was very dry above the inversion with a relative humidity of only 15 to 25 per cent. This in itself is sufficient indication that the upper air had been subsiding and that its high temperature was in part due to this subsidence. Actually the air in front of the trough or occlusion could be traced back to an anticyclonic area about 48 hours previously. The very slight rain associated with the occlusion could hardly have come from the warm air above; its occurrence can more readily be explained by convergence at the trough due to frictional effects,* a fact which finds some corroboration in the cloud base at Utrecht being 3,000 feet below the base of the inversion.

The second influx of warm air during the afternoon of October 2nd which replaced the colder air in the rear of the occlusion, although showing temperatures and humidities at the higher levels similar to those at Utrecht earlier in the day, appeared to have a much more definite polar origin than the previous influx. Actually this air mass was in an " isallobaric high " and the conditions were therefore favourable for subsidence.* The low values of the relative humidity on the morning of October 3rd—19 per cent at 800mb. (6,700 feet) at Duxford, and 15 per cent above 804mb. (6,560 feet) at Utrecht—are further indications of the subsidence which must have been effective in order to raise the temperature of the polar air to such a high level.

It would thus appear that the first large rise in temperature was due to an influx of old polar air, forming the occlusion above the first inversion, the high temperature of which was caused by subsidence which had taken place some time previously. This was closely followed by a further influx of polar air of more recent origin above a second inversion which also owed its high temperature to considerable subsidence from higher levels, and it is probable that at the time this process was hardly complete.

F. H. DIGHT, B.Sc.

Note on a Cold Front at Chefoo, N. China, May 15, 1928.

The preparation of this note on the passage over Chefoo, northern China, on May 15, 1928, of a pronounced cold front, has been rendered possible by Lieutenant J. P. Wright, R.N., of H.M.S. *Hermes*, who called attention to its occurrence and kindly supplied thermograph and barograph records obtained on board H.M.S. *Hermes*, which was at Chefoo at the time.

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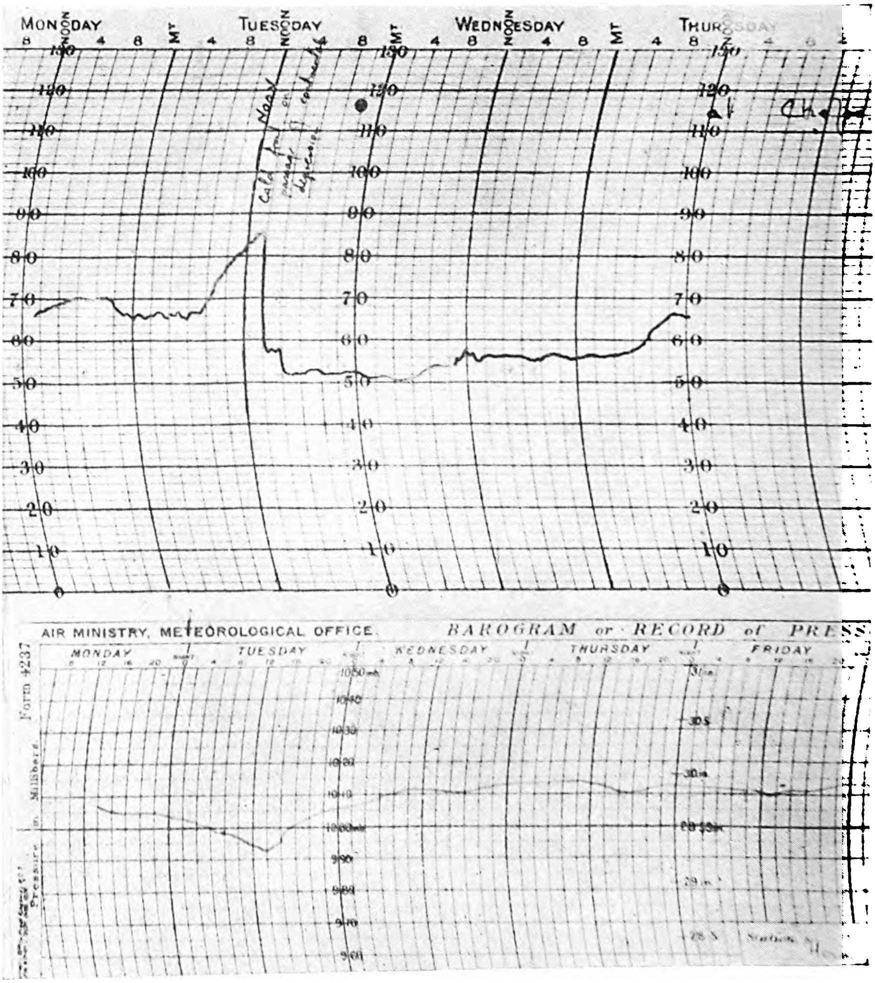
* " The modification of the strophic balance for changing pressure distribution, and its effect on Rainfall." D. Brunt and C. K. M. Douglas. *Mem. R. Meteor. Soc.*, **2**, No. 22, 1928.



Thermogram and Barogram of H.M.S. *Hermes* at Chefoo.

Q.J.R. Meteor. Soc., Vol. **55**, 1929, Plate III

The synoptic chart for the morning of May 15, 1928 (observations for Russian stations being at 0700 local time, and for Japanese stations at 0600, time of meridian 135°W.) reproduced in Plate II., shows the existence of a depression over Manchuria from which a cold front extends in a south-westerly direction down into northern China; this depression had, during the previous few days, moved in a south-easterly direction from northern Siberia. The strong North-Westerly polar current in its rear, which in latitude 50°N. had a temperature of about 25°F., became markedly warmer as it passed down to the latitude of Chefoo, but its temperature was still considerably lower than that of the tropical South-Westerly current before the front. The thermogram in Plate III., which is a record from a mercury-in-steel distant recording thermometer and on which the standard of time is that of meridian 120°E., shows the temperature at Chefoo in the early morning of the 15th to have been about 66°F., but shortly before 0800 insolation became active and just prior to the arrival of the cold front at 1400 the temperature had almost reached 86°F.

The double fall of temperature shown on the thermogram is evidence that the front was probably an accelerating cold front which had, on account of its acceleration, degenerated into a double front,† a type which is quite commonly met with in this country. It is regrettable that there is no anemogram available to reveal the wind changes taking place, but the observer reported that the wind, which during the morning was light South-Westerly, increased in squalls to Beaufort force 6 at 1410 (time of meridian 120°E.) and veered to N., but continued strong for a short time only. At 1500 (time of meridian 120°E.) the wind at Chefoo, as reported in the Zi-Ka-Wei Observatory, China, daily weather report, was NW., force 4. The first drop in temperature, which occurred at about 1400, amounted to 28.5°F., of which it appears that the fall from about 79°F. to 66°F. may have been almost instantaneous, the total fall occupying some 15 minutes. This was succeeded by a period lasting about 1½ hours during which the temperature remained in the neighbourhood of 57°F., corresponding to a zone of subsiding air behind the first cold front. At 1600 the second cold front arrived, being accompanied by a further sudden fall of 6°F. in temperature. The total fall in the two fronts was therefore 34.5°F. The barograph trace, also reproduced (Plate III.) shows that the pressure ceased falling on the arrival of the first front and commenced to rise steadily; the passage of the second front was accompanied by a sudden rise in pressure of about 1½ millibars.

It is evident that the exceptional magnitude of the temperature fall associated with this double front is to be attributed partly to pronounced insolation occurring prior to its arrival, since the South-Westerly current before the front appears to have been blowing from off the continent around an anticyclone over eastern China. A comparison of the temperatures at 0600 on the 15th and 16th, that is, before and after the passage of the front, shows that there is a difference of some 16°F. on the two days and since the night temperatures appear to have been very little affected by radiation, this difference may be taken as a rough measure of the divergence in mean temperature between the South-Westerly and Northerly currents before and behind the cold front, respectively. It is probable also that the high temperature attained before the arrival of the front was in some measure due to a foehn effect, since to southwestward of Chefoo the ground rises gradually to a height of over 3,000 feet at a distance of some 20 miles. The dryness of the air on its arrival at Chefoo, where the relative humidity just prior to the arrival of the front was only 23 per cent, supports this conjecture. In this connection it is interesting to note that at Tsingtao, the position of which is shown in Plate II., the wind at 1500 (time of meridian 120°E.) was S., force 6, with a temperature of 68°F. (as reported in the Zi-Ka-Wei Observatory, China, daily weather report). The S. wind is evidence that the front had not reached that place though it had then passed Chefoo, whilst the temperature was at almost the same level as it was at Chefoo before the pronounced rise set in at about 0800 (Plate III.). Since the wind was blowing from off the sea at Tsingtao, the effect of insolation would be negligible and also there would be no foehn effect; it therefore appears additionally likely that it was the combined operation of these two causes at Chefoo which produced the marked rise of temperature there before the arrival of the front.

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† Bjerknes, J. The structure of fronts. *Meteorological Magazine, London*, **61** (1926), p. 32.

A striking feature of the passage of the front was the absence both of rain and of cloud. The South-Westerly current before the front was, as already stated, exceptionally dry, and it was on that account that no cloud formed, since, under the prevailing conditions, it would have been necessary for the air to be raised to a height of nearly 10,000 feet before becoming saturated.

The outstanding magnitude of the temperature fall (considering for purposes of comparison, the drop of 28.5°F. which occurred at the first front), may be appreciated by a reference to sudden falls of temperature which may accompany cold fronts or squalls in other parts of the world. As regards the British Isles, experience suggests that a drop of more than 10°F. within 15 minutes is not common and falls of more than 15°F. in that period are exceptional. The "Southerly bursters" of Australia are sometimes accompanied by very marked temperature falls; a drop of 37°F. is reported to have occurred on one such occasion though the time occupied by the fall is not known; falls of 22°F. in 15 minutes, and of 18°F. in five minutes have been recorded; the greatest falls occur when the burster arrives about mid-day, on account of the added effect of insolation. Along the south Australian coast-line falls of temperature of more than 20°F. in 10 minutes have occurred at the passage of cold fronts, and a fall of 18°F. in 10 minutes during a line squall at Durban is on record. In West Africa, the rainy season, namely June to October, is characterised by the alternation of the monsoon, which blows from SW. or W., with the harmattan, an Easterly wind. The arrival of the harmattan is marked by a squall accompanied by heavy rain and a sudden fall in temperature. A fall of 11°F. in about 10 minutes has been recorded in these circumstances, and it is probable that still greater falls may sometimes occur.

It may therefore be considered that a fall of 28.5°F. in about 15 minutes as recorded at Chefoo is certainly exceptional, though falls of this order of magnitude are not entirely unrecorded in other parts of the world.

S. P. PETERS.

OBITUARY

Mr. C. M. Powell.

We regret to record the death on December 4, 1928, at Guildford, of Mr. Charles Marten Powell, at the age of 73. Mr. Powell took his degree at Oxford in 1879, after which he studied medicine and practised for a short time in Exmouth. On retiring he went to live at Caversham, and in 1921 he went to Guildford.

Mr. Powell's benefactions were many. He gave £5,000 to complete the endowment of White's Professorship of Moral Philosophy at Corpus Christi College, Oxford, and he was elected an Honorary Fellow of the College in 1910; he also gave £5,000 to the Bodleian Library. At Uppingham, his old school, he endowed an exhibition fund for boys who were in need of assistance. He was keenly interested in the Church of England Waifs and Strays Society, he built a home near Caversham which he ran himself for a time and then presented to the Society. Guildford and its institutions also received many benefactions from his hands.

He was a Life Fellow of the Society and was elected in 1883.

The Rev. R. W. Whiston.

The Reverend Robert Wilmot Whiston died on October 20, 1928, at his residence, Orwell Lodge, Great Shelford, at the age of 73. Mr. Whiston was the eldest son of the Reverend Robert Whiston, J.P., of Rochester, Kent. He was educated at King's School, of which his father was headmaster, and at Repton and Trinity College, Cambridge. He read for the Bar, but he did not practise; he entered the Church instead. While at Orwell Mr. Whiston transcribed and edited a register of the births, marriages and deaths in the parish from 1560 to 1653; a copy of this publication is in the British Museum. He also prepared a list of the vicars of Orwell for display in the Church.

He was elected a Fellow of the Society in January, 1927.

REVIEWS

Observatoire de Zi-Ka-Wei. Etude sur la pluie en Chine. Par le P. E. Gherzi, S.J. I ptie, Les Résultats, II ptie, Les Observations. Atlas, Distribution des pluies en Chine par mois, saisons, année. 3 vols. Chang-Hai (Imprimerie de la Mission Catholique), 1928.

For the first time we are presented with a detailed study of the rainfall of China, accompanied by a pictorial representation of the depth of rain and the frequency of rain-days in the atlas of large-scale, coloured charts. In 1911, when Father Froc's well-known preliminary study appeared, the data were very scanty; the seventeen troublous years since then have added barely enough material to make maps possible. For the effective treatment of China's problems of flood and drought, however, knowledge of the main facts about rainfall is essential, and it was decided to publish the work in spite of the shortcomings of the data. This is therefore a contribution to the reorganisation of China. It is also a contribution of very great value to the science of meteorology, for meteorologically China is one of the most interesting countries in the world, and one about which all too little has been known.

The statistical treatment of the data is very complete and interesting, but the charts offer the fullest return for a detailed study, especially in conjunction with the discussion of the causes of rain on pp. 64-71 of the

"Results." It is customary to classify rainfall into orographic, cyclonic and instability precipitation, but in China this classification is of little value. In the first place, orographic rainfall is of slight importance. On the map of annual rainfall one finds five shaded patches, representing areas of relatively heavy fall. The first, in the south-west, is on the borders of Indo-China. Next is a small area exceeding 60 inches on the south coast at Pakhoi; the third, exceeding 72 inches, occupies part of south-eastern China northward from Hongkong, and almost joins on to the fourth, in eastern China between the Yang-tse and the coast. From here the rainfall decreases rapidly northward, and the fifth local maximum, near Pekin, reaches only 25 inches. Of these five maxima only those in eastern and south-eastern China coincide with even moderately high ground (and here the coincidence appears to be largely accidental) while the maximum near Pekin is limited to the low ground and frankly avoids the hills to the west and north. In western China the isohyets pay no attention at all to the mountain ranges; this may be due less to the absence of an orographic effect than to the absence of stations at high levels, but even the detailed charts, included in part I. of the northern province of Chihli, made possible by the close network of stations established by the Chihli River Commission, fail to show any appreciable orographic effect.

Cyclonic rains fall into two main types, associated respectively with extra-tropical depressions and with typhoons; the former bring the moderate falls of winter and spring in southern China, while the latter bring an important part of the heavy rainfall of summer and autumn on the coast. The extra-tropical or continental depressions are formed in the south-west by an incursion of warm equatorial air towards the boundary of the cold Siberian anticyclone, and the rainfall is heaviest in this warm sector, where in spring it is often associated with thunderstorms. As the depression passes, the cold front brings snowfall, often as an intense blizzard over northern China. After the cold front has passed a spell of intensely cold fine weather sets in, while small ice crystals fall from a clear sky. The total snowfall, however, is very small.

Typhoons visit eastern China mainly in the months of July to September inclusive, coming up from the Pacific Ocean east of the Philippines; when they cross the coast they usually move towards an area of low pressure and there break up. While the typhoon is still active and moving, intense rain falls in violent squalls, the wind velocity sometimes exceeding 100 miles an hour. Under these conditions the gauges, a metre above the ground, cannot record the true falls, yet more than 20 inches in a day have been measured on several occasions. The squalls of rain are believed to be associated with successive upward bursts of air in the centre of the typhoon, of the nature of Sir Napier Shaw's "bubbles." When the typhoon ceases to move and fills up, the wind is less strong and these violent rain-squalls are absent, but steady rain falls persistently for several days. These typhoon rains, rather than the areas of high ground, cause the areas of maximum rainfall in southern and eastern China.

Yet another type is distinguished—monsoon rainfall. One was familiar with the winter monsoon rains of northward-fronting coasts in Formosa and Japan, but here the author describes a type of steady rain with an unpleasantly warm and saturated atmosphere, which results from the convergence over southern China of the south-east monsoon from the Pacific and south-west monsoon from Indo-China, meeting in the zone of low pressure which forms over the interior in summer.

This inadequate attempt to summarise the discussion of causes has left no space for mention of other treasure-trove, but it at least serves to show that the work is no mean contribution to our science.

C. E. P. B.

Geographie des Atlantischen Ozeans. By Dr. GERHARD SCHOTT. 2nd edition, revised and enlarged. Hamburg (C. Boysen), 1926. Pp. 400, illustrated. 40M.

The first edition of this book appeared in 1912 and the second edition has undergone considerable additions and modifications; it is now in its completeness, its wide range of interests and its excellent illustrations and diagrams, an example of German publication at its best.

It begins with a very interesting history of the exploration of the Atlantic, including the discovery of Iceland, south-west Greenland, Labrador, and New Brunswick more than 800 years ago, and bringing out the fact that to the day of his death Columbus thought he had merely reached the east coast of the old world; but he observed the prevailing winds and sea currents, and even the deviation of the magnetic needle. The early attempts at sounding were, not unnaturally, somewhat uncertain; Captain Denham in 1852 recorded 14,180m., where to-day we find about 5,000m.; however, the development of precise methods has been rapid and the number of modern scientific voyages is considerable. Even the nomenclature becomes interesting when treated historically. As late as 1688 Halley called the Ocean between Bermuda and Madeira the "North Sea," the S. Atlantic being generally known as the "Aethiopic Ocean." The name now in use was introduced by Varen in 1650. Attention is also drawn to the great value to-day of the term "European North Sea" now used for half a century by Norwegians to designate the area bounded by Greenland, Spitsbergen, Norway, and the line Orkneys-Faroes-Iceland.

The geology and history of the development of the Atlantic cannot be handled apart from that of the rest of the world, and here too Schott shows the width of his knowledge; incidentally he points out that the idea of moving continents had been put forward independently by Pickering in 1907 before being embodied in Wegener's theory of 1912. The chart on p. 95 illustrating the conditions at the bed of the ocean shows that the similarity between the shapes of the east coast of the American continent and the west coast of Africa and southern Europe extends also to the shape of the mid-ocean ridge which runs from 55°N. to 55°S. and separates deeper regions on its western and eastern sides.

The water at the bottom of the west African deep is cut off by a subsidiary ridge from the Antarctic deep, and is therefore 2°C. warmer near 2°S. than that in the deep off southern Brazil—just as north-west India is protected by the Himalayas from the cold north winds which occasionally freeze over the Helmand river in Seistan. Many other details regarding the deeps, which go down to over 7,000 metres, will be found in Chapter IV., and in the following chapter the physical properties of the Atlantic water are described. Of interest to meteorologists are the surface currents, and the excellent diagrams of the temperatures and salinities at the surface and at various depths. From the first it is clear that over the equator the water is welling up, while in latitudes near 30°N. it is descending; near 25°S. the descent is less marked. The temperatures and the salt-content are higher in these latitudes than anywhere else. It is fascinating to see in the chart of the colour of the surface water (p. 144) that at 25°N. and S. we have the deepest cobalt blue, becoming blue-green at the equator and green in the higher latitudes; the bluer the water, the more transparent and the poorer in the microscopical organisms on which fish live. The association of warmth with salinity is widespread and produces great uniformity in density; hence though we might expect marked warmth of the water near the equator and cold near the poles to set up a general oceanic circulation, velocities are small at depths greater than 500 feet; also above this level the motion of the water is mainly due to the prevailing winds.

The surface water temperatures are important because these control the air temperatures, although in velocities the wind controls the sea; and the ice conditions in the Antarctic vary enormously from year to year (p. 157), so that we appear to have possibilities of explaining seasonal variations of weather over wide regions.

In Chapter VII. we have an account of the life of the Atlantic, from creatures of microscopic dimensions to whales, all being of great economic importance; the annual fluctuations in the quantity of fish caught presumably depend on the distribution of plankton, and the relationship of this with seasonal weather may be close.

The last chapter deals with the traffic of sailing boats and steamships, with telegraph cables, with fisheries and with world politics.

Students of the conditions prevailing in the ocean of air cannot ignore those in the great seas; and meteorologists must know something of oceanography both for the suggestions conveyed by similar features, as well for avoidance of the danger of tracing false analogies.

We have not all time to read a complete treatise on oceanography such as that of Dr. Otto Krümmel, and a very good idea of the subject may be derived from a study of this book on the Atlantic, regarding which more information is available than for the other oceans.

G. T. W.

Cyclones; Théorié Succincte, Prévision et manœuvre préventive. Par M. Rondeleux. Paris (Gauthier-Villars et Cie), 1928. 8vo. Pp. II + 101, pls. 4.

This is an enlarged and revised edition of a work which, published originally in the *Annales Hydrographiques* (1916), was edited by the French hydrographic service to appear as No. 701 of the series of manuals entitled *Instructions Nautiques,* gaining in this form the Janssen prize of the Société de Géographie.

The problem which it attempts to solve is not that of the origin of cyclones, although some theory is included, but the practical problem which sometimes confronts the seaman in tropical waters, namely, how to recognise at the earliest possible moment from the behaviour of the barometer and from some other indications, that a cyclone is not far away, and, having done so, how to manœuvre the vessel so as to avoid passing into the dangerous inner whirl of hurricane winds around the centre. The author has had practical experience of this problem both in the Far East and around Madagascar.

Once the presence of a cyclone has been recognised, the appropriate manœuvres in the open sea depend largely upon which quadrant of the storm is occupied. The quadrants in this case must be fixed with reference to the direction of movement of the storm centre, and not by the points of the compass. Thus, the "dangerous" quadrant is the one which contains winds blowing towards points directly ahead of the centre, and the direction of the wind in that quadrant, as well as the orientation of the quadrant, will depend upon the direction of movement of the storm centre. This is unfortunate from the navigator's point of view; it means that owing to a change of the direction of travel of the storm, he may suddenly find himself in the dangerous quadrant, when previously he had been in one of the "safe" quadrants. It is principally for this reason that so large a part of this manual is devoted to statistics in regard to the paths of storms in different regions and to such seasonal changes of path as are usually found to occur. Such statistics, backed up by observations of the barometer, weather and swell, often enable a good guess at the direction of movement of the storm to be made. Of course where a ship has wireless apparatus, the matter may often be put beyond question by obtaining weather reports from other vessels.

The author of this work appears to merit the honour accorded to him for producing it, but to those whose interest in tropical cyclones is purely meteorological it cannot be altogether recommended: the references to recent work are very incomplete, and the theoretical treatment—based to a large extent upon some lectures given by Angot—is sometimes open to serious criticism. An example may be given: it is stated rather dogmatically that a cyclone must travel along, otherwise it cannot draw in the necessary moist air for its maintenance; on another page we read that the idea of a cyclone as a circular whirl with a motion of translation is no longer held. No attempt is made either to reconcile the two rather contradictory statements or to give some observational evidence of the truth of either, whereas statistics in regard to the changes of intensity of storms which remain stationary for several days, (the author mentions the occasional occurrence of these on another page) or figures showing the wind speeds observed in different quadrants of the faster moving storms, would throw light upon the question whether a cyclone can or cannot be resolved into a circular whirl which travels along.

E. V. NEWNHAM.

Problems of Polar Research. A series of Papers by thirty-one Authors. American Geographical Society: Special Publication No. 7. Edited by W. L. G. JOERG. New York (American Geographical Society). 1928. 8°. Pp. VI + 480, illus.

The recent revival of polar research in the United States gives timeliness to the appearance of this important volume in which, as explained by Dr. Isaiah Bowman in his Preface, "The emphasis is on neither past achievements nor heroic adventure but on the major problems remaining to be solved by further field study, where and by what means those problems may best be attacked, and what manner of co-operation between the sciences most concerned may yield the largest harvest of results."

Dr. Nansen initiates the discussion with a paper on the oceanographical problems of the still unknown Arctic regions and the other thirty writers deal in turn with the geographical, geophysical, geological, meteorological, biological, and ethnographical problems of both polar regions.

Meteorologists have every reason to be pleased with the prominence given to their science. There are four papers devoted to purely meteorological matters, two others treat of sea ice and five deal with questions of research by aircraft to all of which it is fitting that reference be made in this notice.

The first of the purely meteorological papers is by Professor H. H. Clayton on the bearing of polar meteorology on world weather. He traces the main lines of atmospheric circulation and attributes the cold waves which surge over the United States not to the intrusion of air from the surface of the Arctic regions but to radiation from the atmosphere itself, causing portions of the upper air to be cooled so intensely that dynamic heating on its descent leaves it still far colder than the normal surface air. The impulses which set these cold waves or polar fronts in action are in his opinion due to variations in the intensity of solar radiation dependent on changes occurring in the sun itself. Abnormalities of pressure distribution and winds are to be traced to these thermal variations. The details of the processes concerned must be worked out by establishing a network of circum-polar meteorological stations such as that of Professor Hobbs in Greenland.

Sir Frederic Stupart considers the concrete case of the climate of Canada as affected by the meteorology of the Arctic regions. In his paper he points out that the climate of North America is influenced by Arctic conditions everywhere north of the average track of the moving cyclones and by lower-latitude conditions to the south of that track. He cannot agree with Professor Hobbs that the cooling of air on the Greenland plateau is a dominant factor in atmospheric circulation and looks to the regions of minimum winter temperature in north-eastern Siberia and north-eastern Canada as the sources of these pulses. He admits the inadequacy of our present information and hopes for a real advance in knowledge by the establishment of regular meteorological stations in high latitudes. He shares Professor Clayton's belief in the solar origin of climatic variations.

Professor Griffith Taylor treats of the climatic relations between Antarctica and Australia, mainly on the basis of the work of Simpson and Meinardus, but with reference also to preliminary results of other expeditions. He considers that Antarctica is undoubtedly a centre of action which affects Australia and quotes Captain Kidson's application of Bjerknes's theory of polar fronts to the southern hemisphere. In conclusion he says that "it seems obvious that not much progress can be made until a number of permanent stations can be established around the Antarctic continent, so that synoptic charts of the whole southern hemisphere will be available for scientific study."

The fourth paper is by M. Jules Rouch, the meteorologist of Dr. Charcot's expedition in the *Pourquoi Pas?* who describes in clear language the meteorological conditions which have been found to prevail in the region between South America and the Antarctic; but he does not enter into any theoretical relations between the climates of polar and temperate lands.

It is much to be regretted that the full results of the Australian Antarctic Expedition of 1911-14 and Mr. Mossman's discussion of the *Endurance* observations in the Weddell Sea in 1914-16 which we understand is on the eve of completion, were not available for consideration with the other data for the regions concerned. But if they had been there seems to be no doubt that they would only have laid more stress on the need for additional systematic observing stations on the margin of a region which possibly exercises a direct determining influence on the climate of all the southern continents and perhaps of the whole world.

We have not space to comment on the valuable papers on the sea ice of both polar regions nor can we here do more than refer to the papers by Commander Byrd, Sir Hubert Wilkins, Mr. Ellsworth and General Nobile on the methods and prospects of polar flying. General Nobile was bold enough to say that "experts who know how to travel on the ice are no longer needed and men who know how to navigate the air take their place." It is possible that since his expedition in the *Italia* he may be inclined to agree with the views of Byrd and Wilkins who hold that air surveys must be supplemented by studies on the ground in all branches of scientific research and that some expertness in ice travel is very advantageous in the event of a forced landing in the polar regions.

The object of this book is to state problems in order to incite further research to provide a broader basis for general conclusions, and the work of writing, translation (where necessary) and editing is admirably done.

HUGH ROBERT MILL.

Mathematics in Liberal Education. A critical examination of the judgments of prominent men of the ages. By FLORIAN CAJORI. Boston, U.S.A. (Christopher Publishing House), 1928. 8°. Pp. 169. $1.50.

The author of this little book is well known as the author of books on the history of mathematics. The present work is a contribution to the much discussed question of the utility of mathematics as part of general education. In his first chapter Professor Cajori distinguishes three stages in the development of the present attitude towards this vexed question. In the first stage it was held that the mind consists of a group of general faculties or powers—of observation, memory, attention, reason, and perhaps others; and it was held that these faculties could be developed by means of studies which in themselves had no utilitarian value. In the second stage it was maintained that there are no general faculties but a very large number of particular faculties; and a training in reasoning in geometry would not help in reasoning in law. The third stage represents the present situation, and marks a reaction from the extreme position of the second stage. Cajori's discussion of these three stages leaves us with the impression that the science of pedagogy suffers from empiricism. We are even tempted to think that much nonsense is written in the name of "experimental psychology."

In the book under review the author has endeavoured to collect the views of as many varyingly distinguished persons as possible, as to whether or not a training in mathematics is of value as part of a general training of the mind. Whenever he has been able to find definite statements concerning the value of mathematics in the writings of any distinguished author, he has made a note of it. He starts with Greece of the fifth century B.C. and ends with Indianapolis of to-day. Of 731 persons, 603 vote for the educational value of mathematics and 128 against. Of the 395 persons noted under the heading of the 20th century, 322 vote for and 73 against the educational value of mathematics. Thus a counting of heads is very strongly in favour of mathematics.

The main part of the book consists of extracts from the writings of a selected number of the persons consulted. At first sight it might appear that a book of brief selections would be dull reading, but this impression is quickly dissipated by perusal. Much as we should expect, mathematicians such as Isaac Newton, Barlow, Sylvester and Whitehead, and physicists such as Tyndall and Helmholtz strongly advocate the study of mathematics, but it is perhaps a little surprising at first sight to find on their side Martin Luther, Kant, Rousseau, J. S. Mill, Emerson, Wordsworth, Macaulay and Abraham Lincoln. Against them we find arrayed only a relatively few distinguished names, among whom we may mention Swift (Gulliver's Travels), Sir William Hamilton and Oliver Wendell Holmes. The temptation to quote from the book is difficult to overcome. The advocate of mathematics may take his stand with Plato, who according to Tzetzes had over the entrance to his academy at Athens the words, "Let no one ignorant of geometry enter my doors"; or with Immanuel Kant who wrote "I hold that in each separate natural science there can be found only as much real science as it contains mathematics"; or with Francis Bacon, who wrote in the *Advancement of Learning*, ". . . if a child be bird-witted, that is, hath not the faculty of attention, the mathematics giveth a remedy thereunto"; or with Macaulay, who in a letter written during the later years of his life, stated ". . . and I regret still more some habits of mind which a senior wrangler is pretty sure to have." The opponent of mathematics has a narrower range of choice, but can still score by quoting the French classical scholar Scaliger, who wrote "A very bright mind cannot be a great mathematician"; or Sir William Hamilton, ". . . and be it remembered that mathematics and dram-drinking tell especially, in the long run"; or Oliver Wendell Holmes, whose autocrat declared "The power of dealing with numbers . . . is about as common as the power of moving the ears voluntarily, which is a moderately rare endowment."

There is a peevish note in the utterances of the anti-mathematicians, which is completely lacking in those of most of the opposite school. We may contrast their tone with the following extract from Bhaskara, a Hindu mathematician of the twelfth century; "Let a spark of science enter the intelligent mind, and it will increase and spread by its own force. As the drop of oil spreads over the water, as the secret entrusted to the wicked spreads abroad, as the alms given to the worthy poor increase, and as all these, though they be small, spread and increase, so science spreads of itself in the mature mind. To grow in wisdom and strengthen your mental powers, you must read and re-read the mathematicians."

Whichever school of thought he may incline to, the reader of this little book will find in it plenty to interest and stimulate him.

D. B.

Die Dämmerungserscheinungen. Von Prof. Dr. P. GRUNER und Dr. H. KLEINERT. Hamburg (Henri Grand), 1927. 8°. Pp. vii + 124, pls. 6, tab. 11.

The sunrises and sunsets of Switzerland are famous, and Swiss scientists have been diligent in the systematic study of the phenomena. This little book by two Swiss authors is therefore welcome.

The first feature which strikes the reader is the series of coloured illustrations painted by Herr Heinrich Meyer-Bührer. Herr Meyer-Bührer is evidently a skilful observer and his pictures show artistic feeling, but a suspicion remains that the colours are over-emphasized, the contrasts too violent. If the " purple light " really stands out as sharply against the blue sky as it appears in the first plate in the book, why is the phenomenon not better known to the general public and to artists?

The illustrations to a book of this sort should be chosen so as to inspire confidence in their realism. This remark applies not only to colour but to scale. In ordinary pictures we do not expect to see the sky up to elevations beyond 20° above the horizon. If the artist attempts to show pictorially a phenomenon which extends to 45° we shall probably misjudge the scale and assume he is portraying something much smaller. Herr Meyer-Bührer's anxiety to suggest in his pictures more than the laws of perspective will allow, is shown conspicuously in his study of the earth's shadow and the counter-glow. The limit of the shadow is shown as an arc with pronounced curvature; in the picture the radius of the arc is about 25cm. Surely the curvature should not show in the picture any more than the curvature of the horizon. It would add greatly to the interest of the study of meteorological optics if works on the subject could be illustrated by faithful colour photographs and the angular measurements indicated on the margins. To tell the truth a description of changes in the sky is inevitably very dull and it is only by appealing to our own recollection of somewhat similar experiences that a description can be visualised. If the description goes beyond our experience we are lost.

The authors of the work under review have given very complete descriptions of phenomena, but their special object is to place on record the measurements which have been made. The first set of measurements is devoted to the so-called " purple light," the warm colours which are diffused in the western sky after the sun has set. It appears that the purple light is first observed when the sun is between two and three degrees below the horizon and the upper limit descends until it is lost at an elevation of about 10° when the sun is 5° or 6° below the horizon. This statement holds equally for mountain stations and for those at lower elevations. The difference is that at the higher stations the upper limit of the illumination is judged to be nearly 50° above the horizon at first, whilst at places on the plains the illumination does not extend above 30°.

Direct observation shows that the apparent brightness of the " purple light " reaches its maximum when the sun is about 4° below the horizon, but readings with a spectro-photometer indicate that the intensity of the light is falling steadily. It is because the red components of the light decrease in strength more slowly than those of shorter wave lengths that the warm colour develops.

In the section on ray formation in the "purple light" the authors quote some observations made by Smosarski in Pola in the years 1913 to 1920. According to Smosarski the intensity of the purple light fell off steadily from 1913 to a minimum in 1918. The frequency of observations of crepuscular rays in the purple light fell off likewise, but strangely enough the frequency of the converging anti-crepuscular rays increased from 0 in 1913 to 24 in 1918. Smosarski connects this sequence with the increase in the number of sunspots. An alternative explanation that the high dust content of the upper atmosphere after the eruption of Katmai in 1912 might account for the well developed purple light in 1913 is not mentioned. An extended series of observations is desirable. It is worth noting, however, that the anti-crepuscular rays seem to require especially clear air.

The Swiss observations provide further statistics as to the movement of the upper limit of the earth's shadow and as to the progress of the counter-glow which fringes the shadow. The gradual lowering of the twilight arch within which the last signs of daylight are seen is also recorded. The small variation in the sun's depth when the twilight arch is lost and astronomical twilight ends is remarkable. Observations on the Atlantic, 15.6° and 18.3°, give the extremes for the whole world.

The authors devote a section of their work to the theoretical explanation of twilight colours, but a complete mathematical theory is not attempted. The theory of the "purple light" is made to depend on the existence of a hypothetical disturbance layer. This layer is shown in the diagrams as extending from 20km. to 30km. above the ground. Whether the explanation of twilight glows really requires the existence of a layer with a definite base to it requires proof. If such a layer does exist its relation to other types of stratification in the atmosphere deserves closer investigation.

This notice cannot be concluded without some reference to Alpine glows. The authors explain that there are two normal phenomena to consider and one abnormal one which is more likely to impress the public. The first normal phenomenon is the principal glow, which is due to the direct illumination of the mountains by the setting sun and is characterized by clear shadows. This principal glow ends when the mountain tops pass into the earth's shadow. A little later the "afterglow" is seen when such light as is reflected from the snow comes from the twilight glow or "purple light." The abnormal phenomenon occurs in cloudy weather when observers may be misled into thinking the sun has set when it is still above the horizon. When the rays of the sun break through gaps in the clouds the mountains are suddenly illuminated by deep red light; this phenomenon, which lasts perhaps a short time and suddenly disappears, is said to be regarded by the laity as the typical inexplicable alpine glow. Let meteorologists beware lest they fall into like errors.

It is hardly necessary to add that a close study of "Die Dämmerungserscheinungen" would be a valuable aid to any who would try to understand nature in her most beautiful moods.

F. J. W. W.

Les hivers dans l'Europe occidentale : étude statistique et historique sur leur température : discussion des observations thermométriques 1852-1916 et 1757-1851 : tableaux comparatifs : classification des hivers 1205-1916 : notices historiques sur les hivers remarquables : bibliographie. Par Dr. C. Easton. Leyde (E. J. Brill), 1928. 8°. Pp. IV + 210.

Dr. Charles Easton, the author of a valuable memoir on the periodicity of winter temperatures in western Europe, has fortunately followed the advice to publish the historic records collected during his study of the subject. The area dealt with, his "province climatérique" of western Europe, ranges from Toulouse to Bremen and from Greenwich and Angers to Strasbourg. These limits are adopted owing to the necessity of separating the maritime from the continental climates. To increase the comparative value of these records Dr. Easton has devised a method of replacing the general terms of popular weather records by a precise numerical coefficient. The most convenient data for this figure are—the mean monthly temperature, the numbers of days of frost, the number of days without thaw and of those in which the temperature falls below – 10°C., and the mean of the three minima. From these data he calculates for each locality a mean coefficient, a coefficient of intensity, and a coefficient of temperature; and then by weighting the separate localities he determines for each a general coefficient which expresses the severity of the winter for the province. The historic data are unequal and of uncertain value. Some meteorologists have rejected them as useless, but Dr. Easton finds, when estimating their coefficient, that they are more reliable than might be expected.

The longest section of this memoir is a summary of the historic information available for the winters of western Europe, beginning with six records from 396 to 66 B.C., and one for A.D. 51; the main series begins in the year 221. The early English records are taken mainly from E. J. Lowe's "Natural Phenomena and Chronology of the Seasons since A.D. 220" (London 1870). The later records are sufficiently continuous for Dr. Easton to compile a table giving the coefficient for each winter from 1205. The author remarks that the comparisons are based upon the two assumptions that in western Europe there has been no notable change in the climate since the beginning of the Middle Ages, and that the variations are not due to periodicities of any considerable amplitude. His collection of evidence justifies both assumptions. The years in which the English rivers have been seriously frozen are widely scattered through the centuries. He quotes amongst such years, 221, 231, 292, 329, 545, 554, 1408, 1435 (when heavy waggons went over the Thames ice as far down as Gravesend), 1685, 1688, 1788-9, 1855, 1895, while the Thames was frozen in some years which have escaped Dr. Easton's records. These dates indicate no progressive change in climate. Similarly in the table from 1852-1916, based on observatory data, the five years with the most rigorous winters were in order of severity 1891, 1880, 1895, 1871, 1888, while the mildest winter was in 1869, followed by the four less mild in 1913, 1877, 1884, and 1912.

Dr. Easton remarks that as regards general conclusions "the results obtained have nothing definite" (p. 5); but the observations in this province are not evidence against a regular periodicity in the world's climate as a whole. The province lies in the intermediate belt between the maritime and continental climates, and must be expected to share irregularly in their variations. Most of this province might in one year be under maritime control, and the next year under continental. The variations from year to year must therefore be extremely irregular. The conditions are analogous to those of south-eastern Australia, where, as pointed out in a pamphlet on the "Climate of Australia" (Melbourne, 1904, pp. 58-64), Adelaide being under continental and Sydney under maritime climatic conditions, show a regular oscillation which is not shared by Melbourne; for as Melbourne is in an intermediate zone its weather varies irregularly with the shift in position of the continental and oceanic conditions. Dr. Easton's climatic province is one of special historic importance owing to the unrivalled length of its weather records; but it lies in the belt in Europe in which a regular periodicity would be least evident.

J. W. Gregory.

Physics in Industry. Lectures delivered before the Institute of Physics. Vol. V., Nos. X. and XI. X.—The Relationship of Physics to Aeronautical Science. By H. E. WIMPERIS, O.B.E., M.A., F.R.Ae.S. XI.—Physics in Navigation. By F. E. SMITH, C.B., C.B.E., D.Sc., F.R.S. Oxford Univ. Press; London (Humphrey Milford), 1927. 8°. Pp. 54, pls. 4. 2s. 6d.

The fifth volume of "Physics in Industry" includes the tenth and eleventh lectures of a series delivered before the Institute of Physics, the lecturers being the Directors of Scientific Research at the Air Ministry and Admiralty respectively. The latter fact should be, in itself, sufficient to recommend the volume to those who are interested in the application of physical science to such problems as aeronautics and navigation, but the reader should be warned that he cannot expect to find either subject dealt with in any great detail in the course of one lecture. Further, lest he should experience, after reading the lectures, a feeling of disappointment at the progress described, he must remember, as one of the lecturers rightly points out, that many scientific investigations carried out by Government research staffs are of a confidential nature, and that the scientific world is, thus, unavoidably deprived of the results of such work, at any rate for some time to come.

In the first paper Mr. Wimperis selects a few of the more striking results of recent physical research in relation to aeronautics. He begins with a reference to the circulation theory of aerofoils, built up on the work of such investigators as Lanchester and Prandtl, according to which the flow of air around an aerofoil is regarded as the streamline flow of an inviscid fluid which slips over the surface without retardation, together with a "circulation" around the aerofoil due to the tangential forces arising from the shearing of the viscous fluid over those parts which are held by the solid boundary. The latter determine the forces acting on the aerofoil. The theory has been applied successfully to the design of aeroplane wing sections having given aerodynamic properties.

From the fixed wing as used on aeroplanes the lecturer passes on to consider the rotating wing, and describes the "autogiro" designed by Senor de la Cierva, in which the wings consist of four rotating blades like a windmill, and which provides the best known means of studying the performance of rotating wing machines. One of the most striking results obtained with this type of aircraft is that in descending the vertical velocity is only of the order of fifteen feet per second, or about half the speed of fall of a parachute carrying the same load and having a diameter equal to that of the windmill.

The problems connected with the development of wind channel experiments for testing models of aircraft, and for obtaining the characteristics of new wing sections, are next dealt with, and the Yarrow Tank at the National Physical Laboratory, which was originally designed for the testing of ship models, but which has been used in recent years for work on models of seaplanes, is described. Finally, the lecturer refers to the physical problems presented by the aero-engine. Among these are the troublesome phenomenon of detonation and the adverse effect of a rarefied and cold atmosphere on the performance of the engine of an aircraft flying at great heights. The former is overcome by the use of "doped" fuel, while the latter is met by "supercharging" or the creation of an artificial atmosphere of increased density in the engine intake, which tends to maintain an intake pressure at all altitudes equal to that at ground level.

In the second lecture Dr. Smith limits himself to the physical problems connected with the navigation of ships at sea. In addition to a preliminary historical survey of the subject, interest is added to the lecture by the inclusion, in the accounts of most of the navigational devices dealt with, of the part played by scientific research in their historical development.

After referring briefly to the determination of latitude and longitude, which are linked up respectively with Hadley's sextant and Harrison's chronometer, the lecturer devotes some time to an account of the magnetic compass which may be regarded as the first navigational instrument. The development of the compass depended on the growth of knowledge of magnetic phenomena, but it is interesting to note that improvements on the instrumental side did not keep abreast of the increase in scientific knowledge. The state of affairs in 1616 is illustrated by a quotation from Barlowe's "Magnetical Advertisements," which runs: "The Compasse needle, being the most admirable and usefull instrument of the whole world, is both amongst ours and other nations for the most part, so bungerly and absurdly contrived, as nothing more." It was left to Lord Kelvin to re-model the instrument on scientific lines; the Kelvin type of compass, which is described, has been used practically universally until recent years.

The disadvantage of the magnetic compass for steel ships, and especially for submarines, led to the development of the gyroscopic compass. An interesting description of the principles and construction of this instrument is given. Reference is made to the correction which is necessary to the gyro compass when on a ship in motion, due to the fact that the angular rotation recorded is a resultant rotation consisting of that of the earth and that of the ship relative to the earth. The deviation of the resultant axis of rotation from true north or "speed error" is now corrected by a semi-automatic mechanism, another achievement of scientific research, while change of course is taken into account by another mechanism.

From the gyroscopic compass the lecturer passes on to describe the measurement of speed and the development of methods for obtaining accurate soundings at moderate depths and moderate speeds. For the latter Lord Kelvin's depth recorder is widely used, while in recent years there has been much investigation and a fair amount of application of echo sounding.

The last part of the lecture is devoted to the methods used for determining the position of a ship in fog, and to investigations destined to enable the navigator to proceed in safety in fog and through ice-fields. Position-finding is carried out by a radio-acoustic method or by directional wireless. In the former method the waves from an explosion of gun-cotton under water near the ship are received on a number of hydrophones arranged at known distances apart near the shore, and the times of arrival at the various positions are automatically recorded at a central station connected to the hydrophones by electric cables. When the distance is very great, a wireless signal is sent out by the ship at the same time as the explosion, and the interval of time between the reception of the signal at the central station and that of a shock, multiplied by the velocity of sound in sea water, gives the distance of the ship from the sound receiver. Various systems of directional wireless have been developed and it is an interesting point that in the wireless investigations involved in perfecting directional apparatus, much information of interest to physicists, regarding wireless radiations and the constitution of the upper atmosphere, has been obtained.

Two methods for assisting navigation in fog are described. The most important of these is the leader cable system in which the field due to an alternating current in a cable laid on the sea bed along the desired course induces alternating currents in two coils fixed one on either side of the ship. The presence of the cable is detected by signals in telephones connected to the coils through amplifiers, the difference in intensity of the signals from the two coils indicating the position of the ship relative to the cable.

The problem of providing adequate aids to navigation in ice-fields, when fog or darkness renders the icebergs invisible, is one of the greatest importance. Dr. Smith concludes his lecture with a brief description of the lines of investigation which have been pursued to this end. The London Convention (1914) for the safety of life at sea not only provided for the inauguration of an international derelict-destruction, ice-observation and ice-patrol service, but also advised the application of scientific research to the ice problem. The various lines of research followed include the determination of the variation with place and time of the temperature and salinity of the sea water and the detection of icebergs by echoes from sound beams. The lecturer states, however, that attempts to overcome the problem of fog and ice cannot yet be regarded as very successful.

From the point of view of meteorology there is little in either lecture to appeal to the reader who is not interested also in the general applications of physics to the problems of aeronautics and navigation. Either lecturer, however, with more time at his disposal could have shown that meteorology plays a not unimportant part in the problems with which he was dealing.

F. E.

Theory of Continental Drift: A symposium on the origin and movement of land masses both inter-continental and intra-continental, as proposed by Alfred Wegener. By W. A. J. M. van WATERSCHOOT van der GRACHT, BAILEY WILLIS, ROLLIN T. CHAMBERLIN, JOHN JOLY, G. A. F. MOLENGRAAFF, J. W. GREGORY, ALFRED WEGENER, CHARLES SCHUCHERT, CHESTER R. LONGWELL, FRANK BURSLEY TAYLOR, WILLIAM BOWIE, DAVID WHITE, JOSEPH T. SINGEWALD, Jr., and EDWARD W. BERRY. Published by the American Association of Petroleum Geologists, Tulsa, Oklahoma, U.S.A. London (Thomas Murby and Co.), 1928. 8°. Pp. X + 240.

The publication of the third edition of Wegener's "Origin of Continents and Oceans," followed immediately by Köppen and Wegener's striking book *The Climates of the Geological Past,* raised a greater volume of discussion than any other geographical work of the present century. This may have been due in part to the general revival of interest in the whole science of geophysics, but it must be attributed mainly to the startling nature of the theory itself, for continental drift on the scale advocated by Wegener strikes at the root of many old-established conceptions of geology. Hence the American Association of Petroleum Geologists is to be congratulated on its enterprise in arranging this important symposium of international opinion on the subject. The fourteen contributions, some, including the long introductory exposition by Waterschoot van der Gracht, distinctly favourable, others as definitely antagonistic, are impossible of review in detail, but because of its importance for the science of past climates, the reviewer may be permitted to give his impressions of the position in which the symposium leaves the problem.

It is now well known that the earth's crust is composed mainly of two dissimilar materials, known for convenience as *sial* and *sima.* Sial is the material of the great continental blocks; it is a little lighter than the sima, which underlies the continents and forms the floor of some at least of the great oceans. Sial, typified by granite, is a true solid; sima, best known in the form of basalt, answers as a solid to any tests to which we can apply, but under enormous pressures it is believed that it can behave as a fluid—sometimes; the significance of the qualification will appear later. At these times the continents may be regarded as plates of wax floating in a sea of treacle, and if the forces acting on them are sufficient, they can drift.

There are several arguments in favour of their having actually drifted. Mountain ranges like the Alps, the Andes and the Himalayas have resulted from the compression of great stretches of country, slabs of continent having been piled one on another until the margins of the folded zone have approached several hundreds of miles nearer together. Similarly, the great African Rift Valley apparently represents the beginning of a split along the length of Africa. Another argument, which forms the starting point of Wegener's "Origin" is the remarkable similarity of outline between the Americas on the one side and Europe-Africa on the other.

Arguments are many; the great gap in Wegener's exposition is the lack of a force which is capable of moving mountains. Although theoretically, and under certain conditions, a fluid, the sima at present offers a resistance on which the puny tidal and gravitational forces invoked could not make the slightest impression; effectively it is a solid. Here comes in a theory elaborated by J. Joly, whose recent "Surface History of the Earth" surpasses even Wegener's "Origin" as a romance of science. The earth's crust contains radio-active matter, and this generates heat. The heat generated in the continental blocks can escape through the surface, but if the calculations are correct, the heat generated in the great thickness of sima is more than the surface as now constituted can dispose of, even under the oceans. The sima must become continuously hotter, with the inevitable result that it must melt. Fusion begins at a great depth, and extends gradually upwards until it reaches nearly to the surface. Loss of heat can now proceed more rapidly, and the upper part of the ocean of sima begins to solidify. These cooled masses are heavier than the liquid sima, and sink to the bottom, the process continuing until the whole mass is again solid, when the heating up recommences. A complete cycle runs into many millions of years, commensurate with a geological period.

Joly's brilliant conception explains much. When the sima is liquid, it is light, and the continents sink down into it, causing periods of great marine transgression. As it solidifies and contracts, the continents rise high, and the stresses of contraction throw their margins into the great folds of mountain ranges. During the periods of fusion the sima offers a greatly decreased resistance to continental drift, while the tidal movements within it are exaggerated, and so provide the occasion as well as the opportunity for such drift. Moreover it appears that such drift is necessary to provide an outlet for the heat generated in the sima below the continents, which would otherwise melt beneath our feet. None the less, the forces available apparently remain inadequate to their gigantic task. This applies especially to the gravitational forces acting towards the equator, on which Wegener relies for the breaking up of his great antarctic "Pangaea" over which developed the Permo-Carboniferous ice sheet of the southern hemisphere. Relative east-west movements of the continents have some, though speculative, geophysical basis; north-south movements rest almost entirely on arguments as to past climates. Several contributors to the symposium consider that Wegener's treatment of this aspect of the problem, though ingenious, is open to many grave objections. Moreover the mechanism described by Joly, which does so much to make the east-west movements more plausible, also necessitates great changes in the heights of the continents, and the proportions of land and sea, which would involve corresponding changes of climate, of which Wegener takes little account.

The able geologist who opened the discussion sums up at the end. Generally Speaking, he favours the theory, but he concludes: "This entire symposium stands as a token of the insufficiency of what we have been teaching in the past to explain the facts, and also, of our inability to make our new attempts at an explanation fit in with everything which we now believe to be a fact either in geophysics, geology or biology. . . . The more deeply we think and search, the more the problems multiply. . . ."

C. E. P. B.

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AMATEURS AS PIONEERS

(An Address delivered before the Royal Meteorological Society on Jan. 16th, 1929)

By SIR RICHARD GREGORY, D.Sc., LL.D., President.

When the Fellows of this Society did me the honour to elect me as their President, I trust they realised that I possess no special meteorological knowledge to qualify me to occupy this distinguished position. In common probably with most of the Fellows, my interest in meteorology began by taking the usual daily readings of rainfall, pressure and temperature. These observations seemed to bring physical instruments in closer contact with natural events than did the laboratory work in those days; and when I understood that such records were of service in the production of composite maps of atmospheric conditions and movements I was naturally led into the wide realms of geography and physiography. It was thus through meteorology that I was introduced to the nature and significance of careful observation; and my interest in the science has increased with increasing years. My understanding has unfortunately not undergone corresponding development with the growth of some of the specialised departments of meteorological knowledge. In these fields I am a spectator only, watching an intricate game without being familiar with all the moves in it.

It is a far cry from the simple interests of the voluntary meteorological observer to the activities of professional meteorologists and the subtle applications of mathematics in the analysis of observations and synthesis of principles which now characterise many of the contributions to our *Journal* and *Memoirs*. It should be remembered, however, that some of the most important of these represent research undertaken purely for the love of the subject, and, therefore, appropriately described as the work of amateurs. Though the word amateur is commonly used disparagingly to signify a superficial student or worker, its correct meaning is one who loves or is fond of anything, or cultivates a subject as a pastime, as distinguished from one who prosecutes it as a professional occupation. In this sense every scientific worker is an amateur in any field of activity in which he is interested outside that in which he is professionally engaged.

It is to the glory of British science that most of its inspiration, and many of its greatest achievements, have come from the pioneer work of amateurs. Our own Society is very largely an association of amateurs; and any suggestion of a supercilious attitude towards them from the purely professional side cannot be entertained for a moment. We are joined together with one interest in common—that of the advancement and extension of meteorological knowledge—and any original record or device which will promote this aim is just as welcome as a profound paper on certain correlation coefficients or an original contribution to meteorological theory involving a knowledge of higher mathematics for its comprehension.

So long as the desire for progress is within us all, there can be no conflict of interests between amateur and professional meteorologists. Every great movement—scientific or otherwise—begins with the assembly of apostles and disciples in the spirit of fellowship, and it is only at a later stage that a professional class is created. Just, however, as Huxley said that science "commits suicide when it adopts a creed," so a scientific society loses its soul when devotion of its fellows to their subjects fails to find opportunity of expression on account of the predominance of highly technical or professional themes.

The position is, of course, different in societies or institutions in which professional qualifications are a condition of admission. In such organisations it is appropriate that communications to their meetings should be specialised and technical. It is possible that in the course of time an institution of applied meteorology will come into existence, just as chemistry has given rise to societies concerned with chemical industries, and the Institution of Electrical Engineers had its origin in physics. Until such a fission naturally occurs in our society, it is my view that papers presented at ordinary meetings should usually be such as can be comprehended and discussed by a fair proportion of the Fellows. If a subject is so technical that only a few people can follow it intelligently or offer useful comments upon it, then obviously it is better discussed freely around a table than in the general meeting-room.

On account of the specialisation which is essential to research to-day, every scientific society is faced with the problem of arranging its meetings so that the general body of fellows may be actively interested in them. When little consideration or none is given to the mental reactions of the fellows, then meetings must be sparsely attended, and the society is neglecting one of its main functions, namely, to stimulate interest and inquiry in as large a group as possible. The alternative policy is to form specialised groups within a society, or to create a new association of unspecialised or amateur observers, as was done some years ago when the British Astronomical Association began its successful career.

Until relatively recent times all scientific societies were organisations of amateurs. After the establishment of the experimental method in science in the first half of the seventeenth century, investigators began to form themselves into groups, each contributing to the common stock, so that the benefit of intellectual communion was added to that of contributing knowledge for use in common. Until that period a mastery of Greek and Latin was necessary for the reading of works of philosophers, but when the book of Nature was opened, and it was found that the facts of experimental science could be comprehended by any earnest student and expressed in the mother tongue, a new epoch of intellectual activity was opened. It was thus, says Dr. Martha Ornstein, in her stimulating work on "The Rôle of Scientific Societies in the Seventeenth Century," recently published, that:

"Experimental science entered the ranks in competition with scholastic learning, and made its strongest appeal not to the erudite university man, wedded to accepted tenets and proud of his place in the the oligarchy of the learned, but to the *unzünftigen*, non-professional layman, hitherto excluded from the privileges of mental activity. . . . This love of science developing among non-university men created the type of the science-loving amateur so characteristic of the latter half of the seventeenth century. Amateurs in science —'amateurs' in the accepted sense of the word denoting those that 'practice their art not as a livelihood, but for the love of it'—were to be found in many places and among many classes of people in the latter part of the seventeenth century, mainly, of course, in circles which were sufficiently wealthy not to feel the immediate urgency of gaining a livelihood, and had therefore sufficient leisure to follow their inclinations."

In the first half of the 17th century the English universities provided but meagre and ill-equipped means for the prosecution of scientific studies. They stood, indeed, aloof from the principles of the "New Philosophy," if not actually in opposition to its tenets. We must, however, remember the presence of acute religious controversies, the mainspring of the prevailing hopelessness of the re-adjustment of opinions, whether political or social. At Oxford the Laudian Statutes (1636) inculcated the authority of Aristotle, and importance of dialectics. The same, or kindred promulgations, applied also to the universities of Cambridge, Glasgow, Dublin, Edinburgh. The following summary of the situation as affecting the course of instruction in European universities would appear to be well warranted. "It would thus seem," says Dr. Ornstein, "from the slight progress of the universities along lines of experimental science, from the fact that the greatest scientists of the age were not affiliated with them, from the many criticisms levelled against them, and from actual evidences of their conservatism, extending even into the eighteenth century, that the universities in the seventeenth century did not lend to science that encouragement which it needed in order to take root in them."

It was in such circumstances that the drift of men concerned with the implications of the new learning—working more or less unattached, and, shall we say, in amateur modes—set from the home centres, towards London; later, a consolidation of effort took shape in the foundation of the Royal Society, springing from informal meetings of "diverse worthy persons." Bishop Sprat writes (1667): "If my desires could have prevailed with some excellent friends of mine who engaged me to this work there should have been no other preface to the 'History of the Royal Society' but some of Bacon's writing." As might be expected, we find amongst the early members of the Society, apart from such pioneer amateurs (in our sense) as Wren, John Wallis, Wilkins, Robert Boyle, Evelyn, Hooke, Goddard, Petty, many dilettanti, to wit: Kenelm Digby, Edmund Waller, Denham, as well as noble and other aristocratic adherents, yet all served to promote the advancement of natural knowledge.

Long before instrumental records became a part of meteorology, there was a vast store of weather lore derived from observations of effects of atmospheric changes and seasons upon plant and animal life. Upon this type of contribution, exemplified by Gilbert White's "Natural History of Selborne" and Linnaeus's "Calendar of Flora," which was adapted to our islands by Benjamin Stillingfleet in 1759, has been built the very valuable series of reports of phenological observations which we now owe to Mr. J. E. Clark, Mr. I. D. Margary, Mr. R. Marshall and Captain C. J. P. Cave. These records provide a mass of material for reference of substantial practical importance, as well as of scientific interest. In a stimulating address given recently to the Biological Society of the University of Manchester, Mr. Clark traced the history of phenology and its developments in this and other countries. Co-ordination of the observations began under the Rev. T. A. Preston in 1875; and the "New Series" published by our Society was organised by Mr. Edward Mawley in 1890, and carried on by him until 1910, since when his successors have most worthily continued and extended the scope of the work. The records enable averages of plant events to be determined for thirty or thirty-five years within an accuracy of a day or two, which is a remarkable result from observations made by voluntary observers in many parts of the country. There is still much to be learnt as to the influence of electrical and other obscure climatic forces upon such events, but the material which is annually collated in our reports is of permanent value in showing the response of life to weather conditions, which is the purpose of phenological research.

Apart from such nature study, the earliest known regular meteorological observations in England were made by the Rev. William Merle, first at Oxford and later at Driby in Lincolnshire, from 1337 to 1344, without instruments. The first known systematic instrumental observations were kept by Mr. Locke in Oxford in 1666, but these extended over only two months. Of much greater value are the rainfall records kept by Mr. Townley at Townley, Lancashire, from 1677 to 1704 with some gaps, and the weather register maintained by the Rev. W. Derham at Upminster in Essex from 1697 to 1716. In the second half of the eighteenth century a number of private gentlemen kept records, many of which have survived, but there was no co-ordinating authority. In 1846 James Glaisher became interested in the collection of observations. The Registrar-General had published the mean temperature of York as being five degrees higher than that of London, and Glaisher wrote to him pointing out the physical impossibility of such a difference. As a result, the Registrar-General requested Glaisher to collect suitable observations for inclusion in the "Quarterly Returns of Marriages, Births and Deaths." Glaisher succeeded in forming an organisation of 50 or 60 voluntary observers employing instruments reasonably free from errors.

In 1850 the moribund "Meteorological Society of London" was replaced by the "British Meteorological Society," which later became the "Royal Meteorological Society." One of the earliest members was Glaisher, who promptly initiated the network of Climatological Stations which the Society maintained until it was taken over by the Meteorological Office in 1912. Concerning this organisation Symons was able to state in his Presidential Address in 1881: "We have organised perhaps the most rigorously uniform, and most nearly perfect set of Second-Order Stations in the world."

The systematic collection of rainfall records followed a different course. G. J. Symons, who had been interested in meteorological phenomena when quite young, became a meteorological reporter for the Registrar-General in 1857. Great droughts occurred in 1857, 1858 and 1859, and after the last year Glaisher, in the "Quarterly Returns" of the Registrar-General, doubted whether the great deficiency of the past few years would ever be made up. In consequence of this remark Symons, at the age of 22, collected and published in the *Builder* a summary of the rainfall of 1859. In the following year he collected 168 records from England and Wales and issued them in a quarto pamphlet entitled "English Rainfall, 1860." He was also interested in the collection of statistics of thunderstorms and thunderstorm damage, and his first paper, "On the Thunderstorms of 1857" was read before the Meteorological Society on June 9th, 1858. The acquaintance with observers which he gained during this work greatly facilitated the subsequent collection of rainfall statistics.

In 1860 Symons joined the Meteorological Department of the Board of Trade under Admiral FitzRoy, but his thunderstorm and rainfall organisations took up so much of his time that he resigned his post in 1863.

The first volume of "*British Rainfall*" was published in February, 1862, with the title "On the Distribution of Rain over the British Isles during the Years 1860 and 1861, as observed at about 500 Stations in Great Britain and Ireland." The preface stated that the small volume for 1860 had been in such great request that he had resolved to publish one annually in future. The volume for 1860 and 1861 was limited to annual totals, and extended to 18 pages only, but the full monthly tables were included in a report to the British Association, which occupied 70 pages. The number of stations continued to grow, many of the gauges being supplied by funds provided by the British Association; unfortunately these gauges were not yet of an approved modern pattern. The "Snowdon" gauge appears to have been first introduced by Colonel M. F. Ward at Calne in 1862, but derived its name from an extensive series of observations started by Captain Mathew on the lower slopes of Snowdon.

"*British Rainfall*" for 1863 contained data for 700 stations, and also the twelve numbers of the newly established "Monthly Rain Circular," which afterwards developed into *Symons's Meteorological Magazine*, now *The Meteorological Magazine*. It also contains a prophetic statement:—

> "Having, in the tables for 1862, described them as 'the product of his leisure hours,' it may not be inappropriate for the author to state that they are so no longer. The development of the inquiry being so rapid that he has been compelled to resign either his other engagements, or *British Rainfall* in all its branches. Unpleasant as it was financially, he did not for a moment hesitate, rather to sacrifice his pecuniary prospects, than abandon an investigation, the ramification and importance of which we cannot yet see."

Dr. H. R. Mill's paper "The British Rainfall Organisation after Fifty Years," published in *British Rainfall*, 1909, from which the above quotation is copied, remarks that:—

> "The year 1865 may perhaps be taken as the close of the first stage in the History of the British Rainfall Organisation. The number of records dealt with exceeded 1,000 for the first time, the importance of uniformity in the size, pattern and exposure of rain-gauges was satisfactorily demonstrated, the system of the observers themselves bearing the greater part of the cost of the Organisation, had been laid down . . . . Nearly one-sixth of the whole number of rain-gauges in the country had been visited and inspected."

In 1869 Symons remarked that "if the present voluntary association is inadequately supported or attempted to be displaced, the system of registration which does not now cost the country a farthing, could only be imperfectly perpetuated at an expenditure evceeding £12,000 per annum." Symons himself declined to transfer the organisation to any Government Office, stating that "we will earn a position far higher than any which the British Association or even Government itself could give us." The extent to which this claim was justified is shown by the steady increase of stations to 1,504 in 1871, 2,145 in 1881, 2,709 in 1891, and 3,506 in 1901, shortly after his death. Symons was succeeded as Director by Mr. H. Sowerby Wallis, who was first associated with the work of *British Rainfall* in the wet year 1872, and retired in 1903, also a very wet year. Dr. H. R. Mill then became sole Director. In 1910 Dr. Mill transferred the property and funds of the Organisation to trustees, and Mr. Francis Druce acted as Honorary Treasurer of the Endowment Fund.

The years of the War brought difficulty to the organisation, and in 1919 it was transferred to the Meteorological Office, the leasehold house, 62, Camden Square, and the Endowment Fund being transferred to the Royal Meteorological Society. The Council have maintained the historical record at Camden Square, commenced by Symons in 1858, while the accumulated funds were employed for the preparation and publication of the "Rainfall Atlas." At first the work continued at the old quarters at Camden Square, but in 1922 the headquarters of the organisation were transferred to South Kensington. It is satisfactory to record that Symons's fears for its future under Government control have not been realised, for the organisation continues to prosper, and the number of records included in the volume for 1927 was about 5,000. Amateurs were indeed pioneers in this great organisation, and it is to their devoted work and sustained interest that we owe all our knowledge of British rainfall.

Another branch of meteorological research which was started by amateurs and is now carried on as part of a professional programme is that of upper air investigations. The first use of kites for meteorological purposes took place in 1749, when Dr. Alexander Wilson and Mr. Thomas Melvill, of Glasgow, raised thermometers into the air by means of several kites joined up on one line. By a remarkable anticipation of modern methods, arrangements were made for properly secured thermometers with paper tassels to be automatically dropped at intervals. A picturesque account of the experiments is given in the biographical account of Dr. Wilson in the "Transactions of the Royal Society of Edinburgh" for 1789, but unfortunately none of the readings obtained are given.

Then, about 1752, came Benjamin Franklin's investigations, by means of kites, into atmospheric electricity, to which I shall refer later. The next purely meteorological use of kites seems to have been in the Arctic (69° 21'N.) in the winter of 1822-3, when Captain Parry and the Rev. George Fisher raised a thermometer to a height of 400 feet by means of a kite. The temperature recorded, 24°F., was the same as that at the surface. In 1847 apparatus was prepared at Kew Observatory for kite ascents, but I know of no results. In 1883-85 Mr. Douglas Archibald investigated the velocity of the wind above Tunbridge Wells by means of kites on steel wire, carrying small Biram anemometers, indicating by means of dials the total movement of the air from the time the instruments left the ground until their return.

In 1901 the British Association and the Royal Meteorological Society appointed a joint committee for the study of the upper air. Mr. W. H. Dines was a member of this committee and soon took charge of its activities. He began in 1902 with kites of his own design at Oxshott; and he carried out ascents from an island in Crinan Bay and from steamships. To keep down expense he designed a special meteorograph, very simple in appearance but so efficient that it was not improved on for 19 years. With the development of motoring, kite wires became dangerous in such a populous neighbourhood as Oxshott was becoming, and in 1906 Dines removed to Pyrton Hill, near Watlington, on the Chiltern Hills, where he continued his researches with the aid of the Meteorological Office. It is interesting to recall that a letter to *The Times* in 1903, pointing out that kite-flying at sea would add greatly to the pleasure and excitement of yachting, attracted the attention of Captain C. J. P. Cave, who set up a kite station on his estate at Ditcham Park, Petersfield. Other persons and institutions, such as the University of Manchester, joined in the investigation, and organised investigation was undertaken successfully on days appointed by the International Commission for the Exploration of the Upper Air.

Kites are only able to reach comparatively modest elevations; free ballooons are much less trammelled. The early ascents were all by means of manned balloons. The first manned balloon flights on which meteorological instruments were carried were made in 1784 and 1785 by Dr. John Jeffries, an American citizen, who had taken up residence in England. The full report, presented to the Royal Society, bears the title:—" A narrative of the two aerial voyages of Doctor Jeffries with Mons. Blanchard; with meteorological observations and remarks." The first voyage on the 30th November, 1784, from London into Kent: the second, on the 7th January, 1785, from England into France" (London, 1786). On the first flight the barometer fell from 30 inches to 21.25, and the thermometer from 51 to 28°F. Full meteorological observations were taken, but the author remarks that "as the Public are no way interested in them, it would not become me to mention them here." On the second flight only a barometer was carried, but this instrument showed a fall of pressure from 29.7 to 23 inches. The voyage was less scientific but more sensational, and the adventurers arrived without the majority of their clothing.

The British Association took up the subject about 1850, and in 1852 Welsh made four ascents from Kew Observatory. An account of the scientific results of these ascents was given by Sir Napier Shaw in the *Meteorological Magazine* for July, 1926; the greatest height reached was 22,000 feet, and it is remarked that on each occasion there was an inversion of temperature below 10,000 feet, probably the first determination of an inversion in the free air. Between 1862 and 1866 James Glaisher and Henry Coxwell, again for the British Association, made 28 ascents in the course of which they collected a considerable amount of data. Manned balloon ascents are expensive for meteorological research, however, and their use in this country came to an abrupt end with the loss of the "Saladin" and the death of Walter Howell, M.P., in 1881.

Towards the end of the 19th century, the use of the sounding balloons carrying meteorographs was developed on the Continent. The meteorographs used were heavy and expensive, and correspondingly large balloons were required; in this country, owing to the large percentage of losses in the sea, the method was not practicable until W. H. Dines devised his light meteorograph, weighing just over two ounces, which could be cheaply produced and was yet accurate. Dines carried out a number of ascents at Pyrton Hill after 1906, and many others were carried out by C. J. P. Cave at Ditcham Park. Cave also developed the study of upper winds by means of "pilot balloons" without instruments. His book, "The Structure of the Atmosphere in Clear Weather" is still a classic. Cave also carried out pilot balloon ascents in Barbados during the International Week, December 6th to 11th, 1909. Since then sounding balloons have enabled temperature observations to be made up to heights of 15 miles or more and on many occasions up to 12 miles.

Mention may appropriately be made here of the observatory on Ben Nevis, at a height of 4,406 feet, the establishment of which was undertaken by the Scottish Meteorological Society at the instigation of Alexander Buchan. Eye readings were made hourly, day and night, from 1883 until the end of September, 1904. The work then lapsed, but the Government had intended to carry it on, and it was only as the result of a misunderstanding that the

necessary funds were not provided. The results fill a series of volumes in the "Transactions of the Royal Society of Edinburgh." It may be added that Buchan was the first recipient of the Symons Medal in 1901.

A method of investigating the direction of upper winds, which was used extensively during the War, is the observation of smoke clouds produced by the bursting of shells fired from high-angle guns. This method was first suggested by Sir Francis Galton, who reported to a meeting of the Meteorological Council on July 20th, 1881, that he had made inquiries of Captain A. Noble, C.B., F.R.S. (Sir Andrew Noble) "on the possibility of forming a smoke cloud at a considerable altitude for the observation of upper-air currents by firing a small shell, with a bursting charge, from a seaside station." An account of the enterprise was given by Colonel E. Gold in the *Meteorological Magazine* for December, 1926. Some experiments were made at Newcastle in January, 1882, when the shells burst at a height of 9,500 feet. Further experiments were made in 1884, and they appear to have been quite successful, but the matter was then dropped, mainly because it depended chiefly on the initiative of Sir Francis Galton, and by that time his energies had been diverted into other channels.

Observations of the movements of clouds in relation to wind near the earth's surface or in the upper regions of the atmosphere had, of course, been made long before the suggestion was put forward to produce artificial clouds in order to study such currents. Lamarck's classification of clouds in 1801 and Luke Howard's essay "On the Modification of Clouds" two years later helped to give precision to such descriptions. There is no more fascinating study in meteorology than that of thunder-clouds and their electric charges, to the origin and nature of which the Director of the Meteorological Office, Dr. G. C. Simpson, has made such noteworthy contributions. The theories of positive and negative polarity involved in the discussion of the subject date back to the first half of the eighteenth century, at a time when electricity and magnetism were regarded as separate sciences, and were studied, so to speak, in water-tight compartments. Right throughout the eighteenth century electricity was the subject of investigation by many students of science, both professional and amateur, but one of the most interesting chapters in its history is that connected with the idea of the identity of the electricity from electric machines and lightning, and the possible protection of buildings and ships from the destructive force of lightning, with which the name of Benjamin Franklin is associated. You may remember Turgot's epigram: "He wrested from heaven its thunderbolt and from tyrants their sceptre," and it is worth recalling that Franklin's lightning conductor was the first example of the application of a knowledge of electricity to man's use. A century ago, Sir John Leslie, in a Review of the Progress of Mathematical and Physical Science during the Eighteenth Century, published in the "Encyclopædia Britannica," said: "Electricity has from very small beginnings risen in the space of a little more than half a century to the rank of a Science, superficial indeed, but full of interest and splendour." Nearly all the progress, he notes, was due to amateurs, among whom were Francis

Hawksbee, at one time curator to the Royal Society, Stephen Gray, the pensioner of the Charterhouse, Desaguliers, son of a French refugee, Captain Dufay, of the French Army, and Otto von Guericke. It is from Gray and Desaguliers we get our terms conductors and non-conductors and insulation, and to Dufay we owe the idea of vitreous and resinous electricity.

Franklin's interest in electricity was evoked by a lecture he heard in 1746 at Boston, Massachusetts, and his experiments and reflections were made known to the English botanist, Peter Collinson. It was in his letters he uses the terms positive and negative electricity, and suggests the identity of electricity and lightning, finding similarities in the colour, the direction taken by sparks, and effects on metals and animals. He then suggests erecting a pointed iron rod in a tower or a steeple to draw off electricity from the clouds, and this epoch-making experiment was first made at Marly outside Paris by the French botanist, Dalibard, in May, 1752. Franklin's own famous kite experiment at Philadelphia was made in the following month, and in 1753 he was awarded the Copley Medal of the Royal Society. From this time onwards the demerits and merits of lightning conductors occupied a prominent place in scientific discussions. St. Paul's Cathedral was provided with them, as was Purfleet Powder Magazine, and it was over the question as to whether the conductors should end in knobs or points that a controversy arose which became so acute that King George III. tried to convince Sir John Pringle that knobs were right, eliciting the well known reply of Pringle: "Sire, I cannot reverse the laws and operations of nature."

An almost forgotten application of the lightning conductor was the chain of copper links stowed in a box on board H.M. ships, but which on the approach of a thunderstorm was hoisted to the mast head with the lower end trailing overboard. Sailors were actually killed by lightning while hoisting these chains. It was, I believe, Dr. Sir William Watson, Franklin's friend, who suggested this type of conductor for ships, but seamen owed far more to a later amateur experimenter, the Plymouth surgeon, Sir William Snow Harris, who introduced the copper tape running from truck to keel down the mast and connected firmly to copper bolts passing through the keel. To those interested in the history of the destruction wrought by lightning and the introduction of the lightning conductor the works of Snow Harris are of great value, while Weld, in his "History of the Royal Society," tells the story of the controversy referred to. Franklin himself took no great share in the arguments, and in 1777 wrote to Dr. Ingenhousz from France: "I have never entered into any controversy in defence of my philosophical opinions: I leave them to take their chance in the world. If they are right, truth and experience will support them; if wrong, they ought to be refuted and rejected. Disputes are apt to sour one's temper and disturb one's quiet." It was just about a century after Franklin's letter that the Royal Meteorological Society began its exhaustive inquiries into the subject of lightning rods, and from those inquiries sprang the rules which guide those responsible for protecting our buildings and monuments to-day.

The electrical condition of the atmosphere leads naturally to consideration of the ionized layer of unknown thickness which is about 40 to 50 kilometres above the earth's surface by day and about twice that altitude after sunset. Daily variations of the earth's magnetic field seem to be due to changes of electric conductivity in this layer, and it has been established that the electromagnetic waves used in radio communication and broadcasting are reflected to the ground by the layer, undergoing several reflections in transmission over great distances. It is particularly appropriate to refer to this subject in an address concerned with pioneer work of amateurs because they have largely contributed to our knowledge of it. The effect of such a reflecting layer upon electro-magnetic waves was first pointed out from theoretical considerations by that great genius in applied mathematics, Oliver Heaviside, though Balfour Stewart had previously suspected its existence. Heaviside was a retired business man not attached to any academic institution and occupied no official position, yet his work laid the foundation of the modern theory of telephonic transmission. In 1902 he showed that electro-magnetic waves would accommodate themselves to the curvature of the earth in the same way that they follow wires. He added: "There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other." We now know that wireless waves pass around the world through the action of this Heaviside layer, and it is through the pioneer work of amateurs that world communication was established with short waves—300 metres or less in length.

Soon after the War, persons wishing to experiment privately with radio transmission and reception were given "amateur licences" permitting operation on wave-lengths below 200 metres, which were then considered commercially useless. Using spark transmitters, communication was established over distances of up to 3,000 miles in the United States. Towards the end of 1921, American amateurs transmitted to Great Britain on about 200-metres wave-length, thus beginning the investigation of the possibilities of waves shorter than 300 metres for long-distance communication. By the end of 1922, when most amateurs were using valve transmitters, two-way communication between America and Europe was established on a wave-length of 100 metres.

Amateurs then realised the possibility of even shorter wave-lengths. In October, 1924, the first two-way communication in history between Europe and the Antipodes was accomplished by an English and a New Zealand amateur on a wave-length of 80 metres. Communication over 12,000 miles on short wave-length, with the small power used by amateurs, had not been considered possible before this event. From that time active interest was taken by commercial interests in all countries in the possibility of short wave-lengths for long-distance communication. Between 1924 and 1927 amateurs in every part of the world obtained two-way communication with each other on wave-lengths between 80 and 20 metres. Communication between Arctic and Antarctic expeditions and the world was maintained by amateur co-operation, similarly between expeditions in Africa, etc., when the only means of maintaining touch with the outside world was by short-wave amateur radio. The credit of the discovery that radio-communication over long distances could be accomplished by the use of short electromagnetic waves must be given to investigators of the amateur class, and the achievement is one of which they may justly be proud.

In these days the original or efficient amateur worker in any science tends, of course, to be absorbed into industry or a Government office, for there are far more posts which he may usefully fill than existed in earlier times when almost all contributors to the advancement of natural knowledge were amateurs, inasmuch as they were not officially occupied with scientific investigations. Most purely scientific societies were thus founded by amateurs, and out of their work have often grown national offices and university departments, where the work is now carried on professionally. Our Meteorological Office is an example of this course of development, and the Air Ministry, of which it is a part, is another; for the first achievements in artificial flight were made by such amateurs as Otto Lilienthal, Percy Pilcher, Octave Chanute, M. Ader, Santos Dumont, and above all by Wilbur and Orville Wright. S. P. Langley himself, who first demonstrated the practicability of mechanical flight by his experiments on models, was an amateur in this field, for his main work was in spectroscopy and the physics of the air, and his official position was that of secretary of the Smithsonian Institution, Washington.

The younger generation of to-day takes the aeroplane as a matter of course, as we older men took the locomotive and steamship; yet it is probably true that thirty or forty years ago not one man in a thousand really believed in the possibility of mechanical flight. The suggestion that men would circle in the air for six whole days would then have appeared far more chimerical than the proposed Transatlantic liner of a century ago. Mechanical flight, however, has come, through the efforts of interested and persevering amateurs, the great landmark being the famous flights of Wilbur and Orville Wright over the sand hills of Kitty Hawk, North Carolina, on December 17th, 1903. The twenty-fifth anniversary of those four short flights has just been celebrated by a dinner held in the Science Museum, South Kensington, beneath the historic Wright biplane, which has for the time been lent to the British nation by Mr. Orville Wright, and by a great gathering at Kitty Hawk. At the dinner Mr. Griffith Brewer gave an interesting review of the work of the Wrights, while at Kitty Hawk a huge granite boulder with a memorial tablet was unveiled in the presence of representatives of some thirty nations, an interesting feature of this celebration being the attendance of the five witnesses who were present on December 17th, 1903.

The aeroplane did not, however, come through the efforts of one or two individuals any more than did the steam engine, the steamship, the locomotive, or the motor car; and the brothers Wright again and again acknowledged their indebtedness to their forerunners. Without troubling to go back to still earlier times it may be of interest to recall some of the amateurs who during the 19th century attacked the difficult problem of mechanical flight. First in point of time comes the Yorkshire landowner, Sir George Cayley. In an unfinished essay on "Mechanical Principles of Aerial Navigation," written in 1804, Cayley, who concerned himself with both lighter-than-air and heavier-than-air machines, speaks of his conviction that air transport will prove a most prominent feature in the progress of civilisation. Forty years afterwards Henson published his description of an "Aerial Steam Carriage," and in a letter to Cayley he speaks of his collaborator, John Stringfellow, but calls Cayley "The Father of Aerial Navigation."

With the advance of invention, mechanics and engineering, efforts multiplied apace. Flapping-wing machines, gliding machines, kites, and steam-driven machines are all put to the test. The names of Wenham, Mouillard, Hargrave, Le Bris, Penaud, Phillips, Maxim, Langley, Lilienthal, Pilcher, Chanute, are all indelibly written on the history of aeronautics, and to their work the Wrights often paid tribute. Some of them were men of great experience as engineers, but yet it fell to the Wrights, the bicycle makers, to bring to fruition the results of their labours. Reaping where others had sown, they yet by their own exertions garnered a more bountiful harvest, and by their investigations, experiments and trials succeeded where all others had failed. In the course of their experiments spread over some six or seven years, says Colonel Lockwood Marsh, they "confirmed Lilienthal's theory of the reversal of the centre of pressure on cambered surfaces at small angles of incidence; they confirmed the importance of high aspect ratio in respect to lift; they had evolved new and more accurate tables of lift and pressure on cambered surfaces; they were the first to use a movable horizontal elevator for controlling height; they were the first to adjust the wings to different angles of incidence to maintain lateral balance; and they were the first to use the movable rudder and adjustable wings in combination."

The flights of December 17th, 1903, it may be recalled, attracted little attention, but two years later Wilbur Wright flew a distance of 24 miles at 38 miles an hour, and with the first flights of Orville Wright at Fort Meyer, U.S.A. and those of Wilbur Wright at Le Mans in France, in 1908, the mechanically driven flying-machine entered upon its career as a practical means of transport.

It would be easy to extend this survey into many other fields of science, but this is not the occasion to do so. I have limited myself to an outline of what some amateurs have done as pioneers in the conquest of the air and the growth of meteorological science; and I am sure you will agree with me that their work and influence are worthy of all praise. Let the record serve every voluntary observer as stimulus to endeavour, encouragement to endure, and exemplar of what interest and faithful work may accomplish whether with or without original genius.

Finally, I welcome the opportunity of expressing my most sincere thanks to Dr. C. E. P. Brooks and Engineer-Captain

Edgar C. Smith for providing me with much valuable material which I have been able to use in the preparation of this address. Though the scope and general structure are mine alone, yet it would have been impossible for me to bring together much of the historical material without their help, which has been freely and abundantly given to me, and for which I gladly express my obligations and gratitude.

Winter Thunderstorms.

There are a number of areas from which insufficient data have been obtained during the winters for which thunderstorm records have been collected, and, since scarcity of data may be due to lack of storms or thinness of population, it is very desirable that more definite evidence, negative or otherwise, be obtained from these areas before the storm census is finally closed. The districts are specified below. In England and Wales they extend from 10 to 15 miles round the places, and for a similar distance on either side of lines joining groups of places mentioned. In Scotland and Ireland areas are specified by counties. I shall be very grateful if any observers, resident for a number of years in any of the districts, will be good enough to send me their estimate of the number of days on which thunder is heard in their neighbourhood during the six winter months (October 1st to March 31st) on the average in each year. The frequency may be as low as one day in three or four winters or perhaps no winter thunder may be remembered; in any case, the actual experience of the observer will be extremely welcome.

England and Wales :—

Cornwall: Wadebridge, Boscastle.
Devon and Somerset: Lynton, Exmoor, Minehead.
Norfolk: Fakenham, Aylsham.
Cheshire: Malpas, Nantwich.
Lincolnshire: Brigg.
Yorkshire: Pocklington, Kirkby Moorside, Guisboro'.
Westmorland and Yorkshire: Kirkby Lonsdale, Hawes, Brough.
Cumberland: Cross Fell, Brampton.
Northumberland: Rothbury, Wooler.
Cardiganshire: Lampeter, Cardigan.
Carmarthenshire and Brecknock: Llangadock, Brecon.
Carnarvonshire, Denbigh and Merioneth: Llanberis, Ruthin, Bala.

Scotland :—

Counties: Bute, Ayr, Southern Lanark and Peebles.
  Northern Perth, Northern Forfar and Western Aberdeen.
  Eastern Inverness, Sutherland and Caithness.

Ireland :—

Counties: Limerick, Northern Tipperary and Southern Galway.
  Wexford and Southern Wicklow.
  Sligo, Northern Roscommon, Longford, Cavan, Monaghan and Louth.
  Western Tyrone and Eastern Donegal.
  Northern Antrim and Southern Londonderry.

This special inquiry is in no way intended to question records already received from these areas, but aims at securing fuller information where it has not been possible to draw adequate conclusions.

S. MORRIS BOWER.

Langley Terrace, Oakes, Huddersfield.

THE BAKER AUTOMATIC RELEASE FOR DROPPING THE METEOROGRAPH FROM A REGISTERING BALLOON AT A PRE-DETERMINED HEIGHT.

By L .H. G. DINES, M.A.

[Manuscript received Dec. 3, 1928—Read Feb. 20, 1929.]

In making observations with registering balloons it is normally the desire of the observer to reach as great a height as possible, the balloon being allowed to rise until either it bursts or develops a leak. There are occasions when this method of procedure renders the recovery of the meteorograph very doubtful, as for example when the observing station is not far from the sea and the wind is blowing in a seaward direction. Such occasions are very common in England, and in order to meet the difficulty the little instrument here described was designed about six years ago at the old Benson Observatory. It was primarily the design of Mr. H. W. Baker, and since that time has been successfully used a number of times by the Upper Air Section of Kew Observatory and occasionally by Commander Garbett in connexion with balloon soundings made from a ship at sea.

The general construction is shown in Fig. 1, for which illustration I am indebted to Mr. Baker. The instrument which weighs a little less than 1 oz. (25 grammes), is hung between the balloon and the meteorograph, generally just above the latter. The string from the neck of the balloon is attached to the loose ring R at the top, while the meteorograph, bamboo cage, etc., are hung from the fixed ring F at the bottom. The frame ABCD is exactly similar to that of the Dines balloon meteorograph, the two parts AB and CD being stiff while BC acts as a spring hinge between them. The aneroid box X controls the relative positions of AB and CD by means of the spring connexion XY, the latter ends in a threaded rod on which is a milled nut H and a lock nut. The spring hinge BC is so formed that the piece XY is in tension under all conditions of expansion of the aneroid box. Across the top of the frame is hinged the trigger T which normally rests on a catch at D, the ring R is slipped over T and rests in the notch. When the external pressure falls the expansion of the aneroid box opens out the two sides of the frame, T falls off the catch and the ring slips off R and is released. The balloon floats away, while the meteorograph with the releasing device attached falls to earth.

The aneroid box is made of rather thin metal and is sealed up with air inside, so that at atmospheric pressure the two diaphragms are parallel and unstressed and the air pressure is the same inside and out. This of course entails a very large temperature correction, but provides a very powerful control and thereby enables the weight of the instrument to be kept low. It will be seen that the further outwards the nut H is screwed the higher will be the pressure at which the ring R will be released, and it is necessary to calibrate the instrument in order to deter-

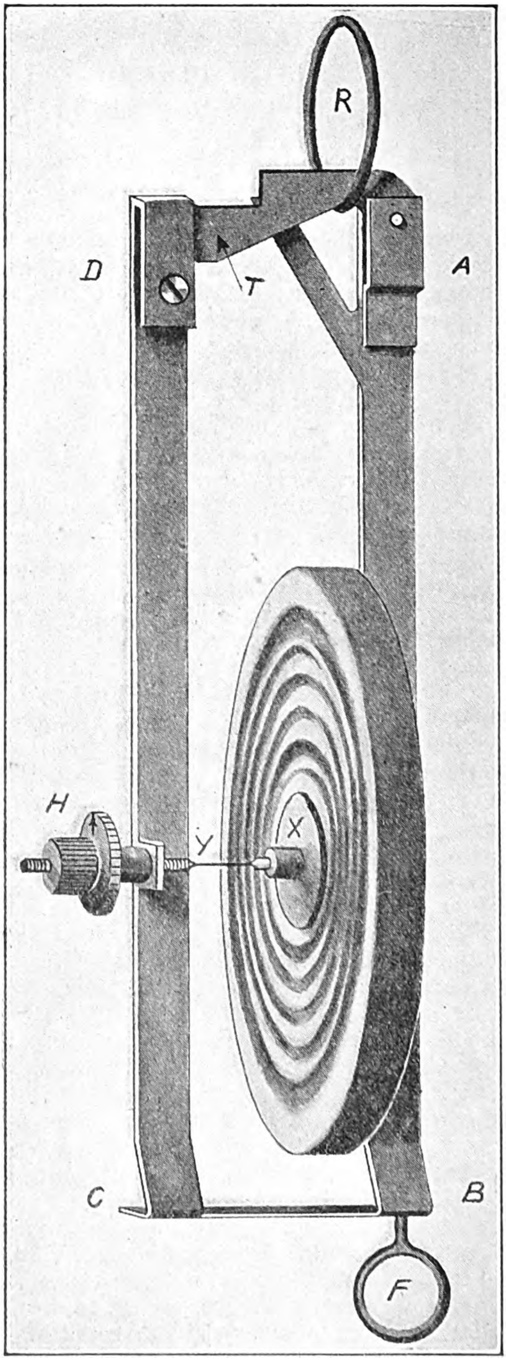
R
D
T
A
H
Y
X
C
B
F

FIG. 1.—Baker automatic release.

mine once for all the relation between the position of H and the pressure of release. If, for example, it be desired that the meteorograph should be dropped at a height of 9 kilometres, it is first necessary to form an estimate of what the pressure and temperature will be at that height on the day in question, and then the requisite setting of H is determined from the results of the calibration test. Since a high degree of accuracy is not needed it is sufficient to estimate the temperature and pressure by the aid of tables of mean values and a knowledge of the surface conditions.

The method of calibration is as follows. The instrument is turned upside down and a weight hung on the ring R of the same weight as that which it will be called on to sustain in an actual flight, that is about 150 grammes. The working parts are oiled and the nut H is adjusted so that the ring is just about to drop. This position of the nut is marked and is henceforth regarded as the datum. The external pressure P_0 and the temperature T_0 at which the test is made are noted. The nut H is then screwed inwards by exactly one turn, the external pressure is reduced slowly and its value noted when the ring drops off, the process being repeated one turn at a time until the working range of the instrument has been covered.

The data thus obtained are plotted on a diagram similar to Fig. 2, as the points $A_0A_1A_2A_3A_4$, etc., which show the pressure at which the ring falls off for each complete turn of the nut at the definite temperature T_0. The diagram has been drawn for the conditions given by $P_0=1{,}000$ mb. and $T_0=292$a. From these points by interpolation it is at once possible to set the nut H so that the ring will be released at any desired pressure provided that the temperature remains at 292a. As, however, we have to allow for variations of temperature as well as of pressure, it is necessary to determine the effect of temperature change on the expansion of the aneroid box, and to this end a similar observation must be made at a lower temperature. It is convenient for the purpose to use the vessel which is commonly used in the calibration of the meteorographs; the temperature of the bath is reduced to about 223a. (−50°C.) and the nut is screwed inwards from the datum by such a whole number of turns as would be expected to cause the ring to fall at a pressure of about 200 mb. The exact pressure at which the ring falls and the temperature of the bath are noted and are shown by the point B_8 in Fig. 2, where it is supposed that eight complete turns were given to the nut. If great accuracy is aimed at, a series of observations must be made at the lower temperature, similar to that already made at normal temperature, but as will appear below quite sufficient accuracy for ordinary purposes is obtained by plotting one point only, as B_8.

From the construction of the instrument it will appear that with any definite number of turns r of the nut H from the datum position, there is associated a definite internal volume of the aneroid box at the instant of release. If, therefore, isopleths of volume can be drawn on Fig. 2, passing through the plotted points $A_0A_1A_2A_3A_4A_5$, etc., we can then determine the number of turns which must be given to H to ensure release of the ring under

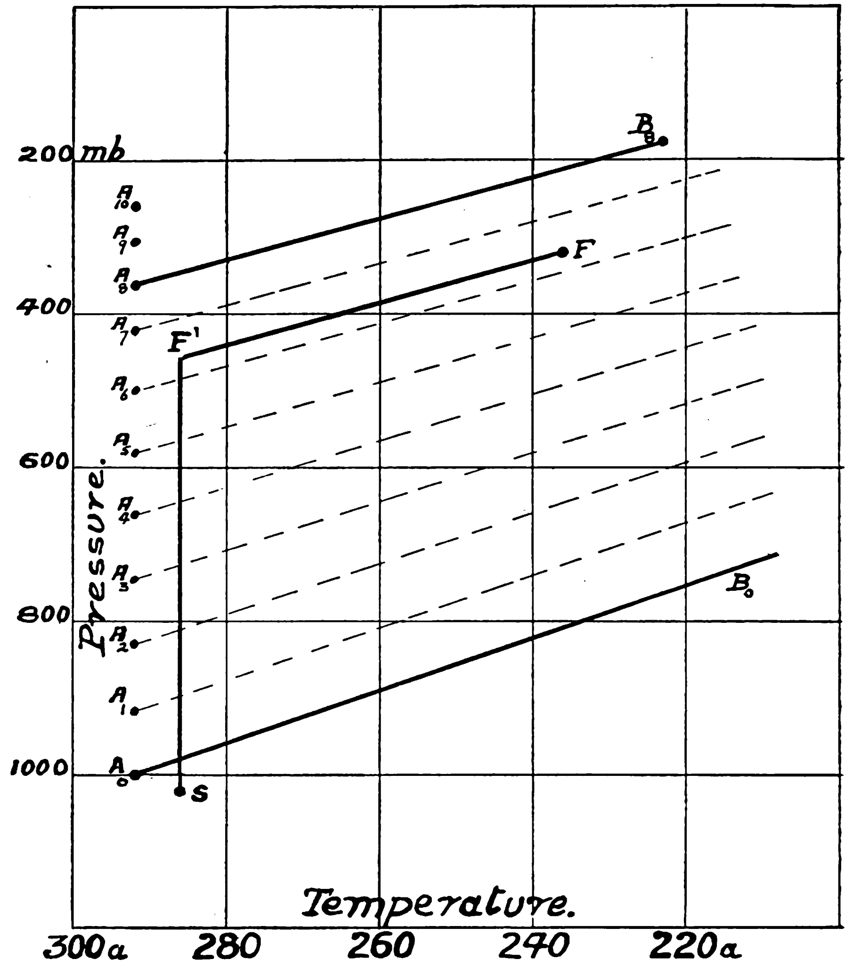

FIG. 2.—Relation between the Pressure and Temperature at the instant of release of the ring and the number of turns of the nut from the datum.

any given conditions of both temperature and pressure. It is clear that one such isopleth must be a curve passing through A_8 and B_8; the next step is to determine the isopleth passing through A_0; this may be done without further experiment, because at atmospheric pressure the aneroid box is nearly unstressed and therefore the pressure inside is very nearly the same as that outside, hence the isopleth of constant volume is determined by the condition that P/T is constant, where P and T refer to the external conditions. This relation gives a straight line which is shown on Fig. 2 by A_0B_0. More detailed tests have shown that the isopleth A_8B_8 is very nearly a straight line, and as extreme accuracy is not required we may draw it as such. With similar limitations we may assume that the other isopleths through A_1, A_2, A_3, A_4, etc., are also straight lines and draw them in by interpolation on the principle of continually decreasing slope between A_0B_0 and A_8B_8.

Suppose now that it is desired to release the ring at a height of 9 kilometres, we first plot on Fig. 2 the expected values of the pressure and temperature there, shown by the point F, say, then draw through F the isopleth of constant volume FF′ by interpolation between the neighbouring lines. Next plot the surface pressure and temperature in the point S and draw through it the ordinate SF′ to meet the other line in F′. By interpolation determine the values of r corresponding with S and F′ (or F) and call their algebraic difference N. In the figure F′ corresponds with a value of r equal to 6.3 and S with one of -0.4, so that $N=6.7$. Strictly speaking, it should be sufficient to set the nut H entirely from the point F′, that is by turning it inwards by 6.3 turns from the datum, but it is not possible to ensure that the instrument will permanently maintain a constant zero under the rough treatment it usually receives. It is better, just before a sounding is made, to determine by trial the position of the nut H when the ring duly loaded is about to fall under the surface conditions of temperature and pressure, and then to turn the nut inwards by N turns from that.

The automatic release described above has been employed about 23 times during the last five years and some record of its actual performance may be of interest. On six of these occasions the meteorograph was never found, but on the remaining 17 it was proved by the record to have released the meteorograph within about 2 kilometres or less of the pre-determined heights. These heights ranged between 4 and 13 km., and as would be expected the accuracy was much better with the lower heights than with the greater. It is probable that a closer agreement could have been obtained if greater care had been taken in forecasting the pressure and temperature at the desired point of release. Generally speaking, little attempt at accuracy was made as the exact height of release did not greatly matter.

DISCUSSION.

Sir **Richard Gregory**: The simple and ingenious instrument described by Mr. Dines should be a very useful accessory to registering balloons. It is often desirable to know the conditions of the upper air at particular altitudes and to have more control over the return of the meteorograph records, and the method of automatic release provided by this instrument seems to secure this with reasonable efficiency. Commander Garbett has had experience in the use of the device at sea and will perhaps be good enough to favour us with a statement of his use of it.

Commander **L. G. Garbett**, R.N.: I do not know if it is generally realised that the method used at sea for obtaining observations by means of sounding balloons is somewhat more complicated than the method used on shore. At sea two balloons, of considerably larger size than those used on shore, have to be used. These balloons are sent up in tandem, the upper balloon being given twice the lift of the lower one. Attached to the balloons are the meteorograph and a sea anchor float made of canvas weighing anything from 3½ to 6 lbs. When the apparatus reaches a considerable height the upper balloon bursts and the apparatus comes down. When the anchor float touches the sea the surviving balloon takes up the lift of the instrument and keeps it from going into the water and provides a mark to indicate its position. Normally the apparatus takes about an hour to go up and an hour to come down, so if there is any force of wind you can imagine that the ship, having released the apparatus, would have to steam many hours in order to recover it. This is not usually practicable, especially if in confined waters, and so it was essential to obtain some device to bring the balloon down in some more reasonable time. For three or four successive summers I have been afloat in one of H.M. ships, and carried out observations with sounding balloons, and on each occasion Mr. Dines provided me with an instrument such as he has described; it always did the trick and never failed me, and although sometimes I anxiously waited for the balloon to descend and blamed Mr. Dines's instrument for not functioning properly, on examining the records afterwards I always found the balloon had been released somewhere about the prescribed height. In 1927 I sent an apparatus up, the device being set to release the balloon at 5½ km.; and the record showed that it was released within 50 metres of this height. There is one question I should like to ask Mr. Dines with regard to the calibration of the instrument—I should be interested to know if, when obtaining the datum for an instrument for use at sea, he takes into account the additional weight of the sea apparatus or takes the 5 or 6 oz. he mentions in the paper as a standard? I should like to congratulate Mr. Dines and Mr. Baker on their ingenuity in devising this useful instrument.

Sir GILBERT WALKER asked whether Mr. Dines had considered the plan of saving weight by using one aneroid to serve both for recording and for releasing—saving weight means a smaller balloon and a saving of cost.

Mr. L. H. G. DINES said in reply: In reply to Commander Garbett—When the instrument is intended for use at sea the final determination of the datum position of the nut H is made with the increased weight hung on the ring, but the number of turns by which H must be rotated from that datum is determined as usual from the original calibration graph.

In reply to Sir Gilbert Walker—It would hardly be desirable to put extra work involving frictional forces on the aneroid box of the meteorograph; such a procedure could only cause needless error in the pressure record. It would be quite possible to construct the automatic dropper on an appreciably smaller scale than has heretofore been done. The dimensions of the instrument were fixed more from convenience in manufacture than anything else, and a reduction in size and weight could be affected without any undue loss of accuracy.

NOTE.—Apparatus intended for a similar purpose was described in the *Journal* in **37**, 1911, p. 247; **38**, 1912, p. 287; and **39**, 1913, p. 61.

SOME ASPECTS OF SURFACES OF DISCONTINUITY.

By C. K. M. DOUGLAS, B.A.

[Manuscript received November 3, 1928—Read February 20, 1929.]

SUMMARY.

The following are the chief points contained in the various sections of the paper:—

(1) Some factors tending to produce sharp fronts at the earth's surface are discussed.

(2) Examples of soundings of upper air temperature through rainy fronts are given. It is found that the surface of discontinuity is normally smoothed through a layer about a kilometre thick, inversions being rare, especially in deep depressions. A considerable thickness of nimbus cloud is often formed below the discontinuity, probably owing to turbulence in air made damp by rain. It is thought that some rain belts, with associated fronts resembling "occlusions," are developed in polar air and are not strictly "occlusions" at all.

(3) Further evidence is given showing that warm sectors are not surface phenomena, but are of fundamental importance in determining the upper air conditions over depressions. It is argued that the fall of pressure in the warm sector in a deepening depression must be due to the spreading over of air from higher latitudes in the upper part of the troposphere and in the stratosphere. The corresponding feature of a developing anticyclone is a spreading over of tropical air at high levels.

(4) Subsidence is discussed in a rough quantitative manner. In a developing anticyclone the downward movement is probably of the order of a kilometre per day at the 3-kilometre level. The development of inversions with dry air above them (comprising a very large percentage of all inversions in the troposphere above 500 metres), is considered to be due to subsidence combined with turbulence up to a definite limit. Emphasis is laid on the importance of both cloud particles and precipitation in preventing dynamical warming at a fixed level by subsidence.

(5) A list of 16 striking wind discontinuities observed by pilot balloons in the British Isles in the last nine years is given, with some remarks on their relation with fronts and surfaces of subsidence.

(6) Turbulence at sloping surfaces of discontinuity is discussed on the basis of a criterion due to L. F. Richardson.

(7) The over-running of warm air by cold air is referred to, and it is thought that except near the ground this takes the form of continuous rather than of discontinuous motion. It is shown that a vertical front of any appreciable magnitude must be very much smoothed out.

An appendix is added dealing with the combination of rotary and translatory motions.

The general line of argument is that the more important pressure changes are due mainly to large-scale horizontal movements at high levels, considered in conjunction with movements at lower levels. When depressions grow deeper the resulting convergence in the lower levels influences the subsequent behaviour of already existing fronts and in certain cases forms new fronts. When anticyclones develop, the subsidence causes inversions to form which are entirely different from frontal surfaces, and in addition the divergence may sharpen up fronts at the boundaries of the anticyclones.

1.1 During recent years large-scale discontinuities or "fronts" have attracted a good deal of attention, partly because of their intrinsic importance and partly because they are rather easier to investigate than most atmospheric phenomena, in spite of their complexity. Upper air observations close to fronts are not yet numerous, since clouds and rain prevent the observations of pilot balloons and make aeroplane flights difficult. Nevertheless at

Duxford, Cambridgeshire, where meteorological observations are taken by the Royal Air Force, quite a number of flights have been made during continuous precipitation, in clouds extending from near the ground to above the highest level reached, about 4 to 5 km. These performances reflect great credit on the pilots. There are also available the observations by means of sounding balloons, but since most of the dates of these ascents are arranged years in advance, only a small proportion of the observations have been made through fronts. J. Bjerknes has recently informed me that he hopes to arrange an intensive attack on fronts and cyclones by means of sounding balloons, but nevertheless it is perhaps worth while at the present stage to collect together the best of the relevant British data and to discuss certain associated problems, though some of the conclusions are necessarily tentative in character.

1.2 The primary cause of fronts is to be sought in the horizontal air movements, associated with large depressions and anticyclones, which bring together masses of air of widely different origin. At the earth's surface the front sometimes becomes sharp (see Fig. 1) with a transitional zone only a few kilometres wide, while on other occasions, especially in the case of warm fronts, the transitional zone has a width of some hundreds of kilometres. In certain cases, including some cold fronts, the temperature difference does not appear at all at the earth's surface, but only up above. Generally speaking, the total temperature difference is larger in the upper air than near the ground, but it is seldom if ever abrupt in character.

Surface Observations.

1.3 A very large number of autographic records is available for the investigation of surface conditions, and it is found that fronts sometimes change their character considerably as they cross the country. In an important memorandum to be published shortly by J. Bjerknes it is shown that a front becomes sharp when the air in the transitional belt is displaced upwards, a process obviously involving convergence and precipitation. The effect of the precipitation itself in further reducing the temperature of the cold air also seems to be important, being sometimes sufficient to change rain into snow. The rain has not the same effect on damp air with a small lapse rate, such as typical equatorial air. When, on the other hand, there is divergence and subsidence the front becomes smoothed out.

Further light has been thrown on these questions in a recent paper by D. Brunt and C. K. M. Douglas,[1] in which it was shown that convergence to a front takes place when the changes in pressure distribution are such that the vector difference of "geostrophic" wind, between places on different sides of the front, is increasing. (In the case of smooth fronts one would choose one's places of measurement outside the transitional zone.) Generally speaking, it is impossible to distinguish between cause and effect. In some cases, however, a changing pressure gradient in the polar current is due to the development or advance of a distant anti-

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[1] *Mem. R. Meteor. Soc.*, **3**, 1928, No. 22.

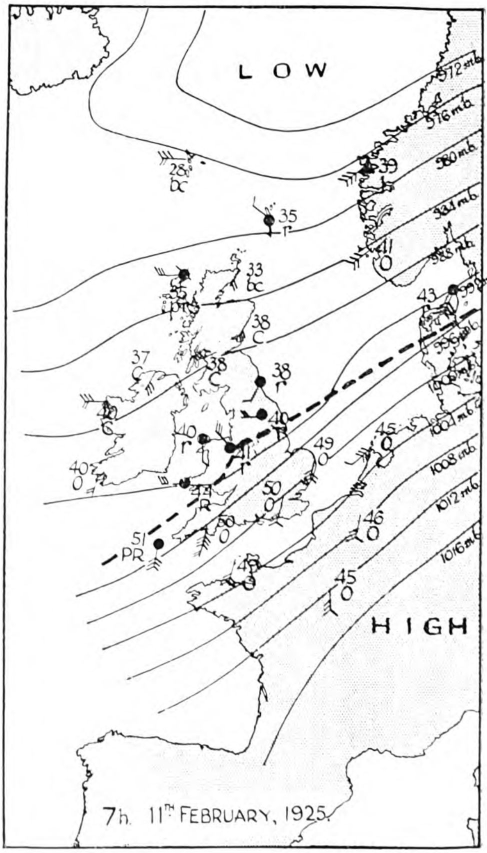

LOW
HIGH
972 mb.
976 mb.
980 mb.
984 mb.
988 mb.
992 mb.
996 mb.
1000 mb.
1004 mb.
1008 mb.
1012 mb.
1016 mb.
7h. 11th FEBRUARY, 1925.

FIG. 2.

cyclone, centred perhaps 2,000 km. away, and itself probably controlled by causes operating over a very large area. In such cases the convergence, the heavy precipitation, and the sharpening of the front, appear to be the *consequence* of atmospheric movements on a much larger scale.

1.4 Surface friction is also an important factor in determining the sharpness of a front. In Appendix I. of the *Memoir* by Brunt and Douglas it was shown that the total flow of warm air into the front is a maximum when the front is parallel to the surface wind in the warm current, and this condition obviously tends to make a front sharp. A fast-moving warm front cuts the isobars at a large angle, and the surface air lags behind and the front is smoothed out. In the case of a cold front it is less important that the surface air should keep up with the front, since if the cold air comes in first at the 600-metre level it will normally descend owing to thermal instability. This is probably the chief reason why cold fronts are on the whole sharper than warm fronts. If, however, the cold air up above is warmed by subsidence, the front may become smooth.

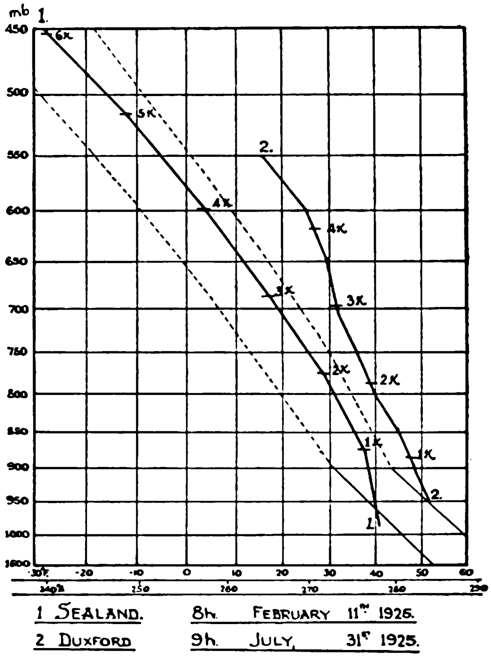
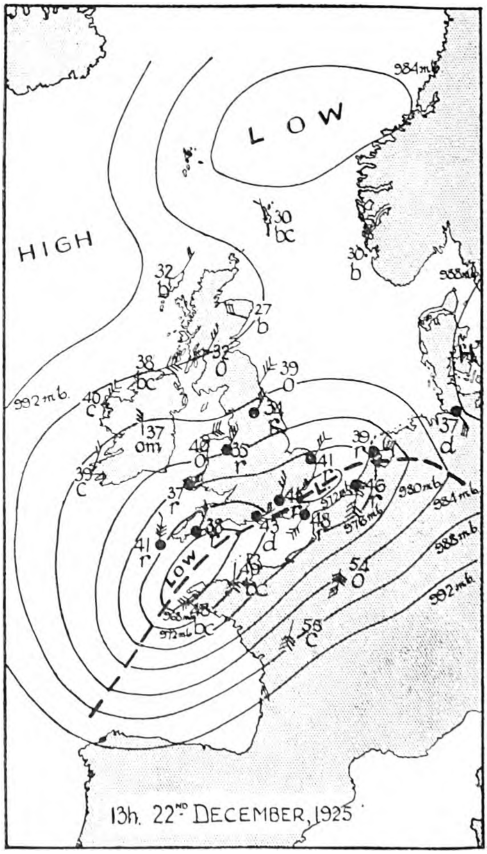


FIG. 3.—Temperature-pressure curves for upper air soundings during rain. The points marked as 1K, etc., give heights in kilometres. The broken lines are "saturated adiabatic" curves. The continuous portions at the bottom of these curves are "dry adiabatic" lines.

In the case illustrated by Figs. 1 to 3 both the factors discussed above were favourable for a sharp front. On the evening of February 10 the geostrophic wind on the north-west side of the front was 12 metres per second from WSW, while at 7h. on

11th there was a zone of practically no gradient. As the front crossed the Midlands and south-east England the accompanying fall of temperature was very large, the temperature in the cold air having dropped to near freezing point, with some sleet or snow.[2]

A good example of a sharp warm front was that of January 28-29, 1927, at Falmouth, previously discussed by the writer.[3] In that case the front had been almost stationary for several hours, and then advanced as a warm front, and both the factors tending to sharpen it were again in evidence. All the really sharp warm fronts which I have noticed at coast stations have been of this type, but at certain inland stations, notably Sealand and Renfrew, purely local conditions may make even a fast-moving warm front sharp, although perhaps rather belated. The convergence associated with a deepening depression does something to sharpen a



13h. 22nd DECEMBER, 1925

FIG. 4.

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[2] See *Meteor. Mag., London*, **60**, 1925, pp. 53-57. This front is one of those discussed by J. Bjerknes in his memorandum not yet published.

[3] *Q.J.R. Meteor. Soc.*, **54**, 1928, pp. 19-25.

warm front, but in order that the front should be really knife-sharp the surface frictional effect must also be favourable.

2. UPPER AIR CONDITIONS DURING CONTINUOUS PRECIPITATION.

2.1 Fig. 3 shows a sounding balloon ascent at Sealand about an hour after the passage of the front of Figs. 1 and 2, during the rain. Considering how sharp the front was on the ground, it is surprisingly smooth up above, with no inversion, but a small lapse rate in the lowest kilometre. I have been informed by L. H. G. Dines that the trace shows no sign of an inversion, and that it would be possible to detect an inversion of even a fraction of a degree. Another interesting example, that of December 23, 1925, is shown in Figs. 4 and 5, and the temperature curve is rather similar to that of February 11. The sounding next day at Sealand, in a small wedge of high pressure in the polar air, is included to show the great contrast of temperature up above.

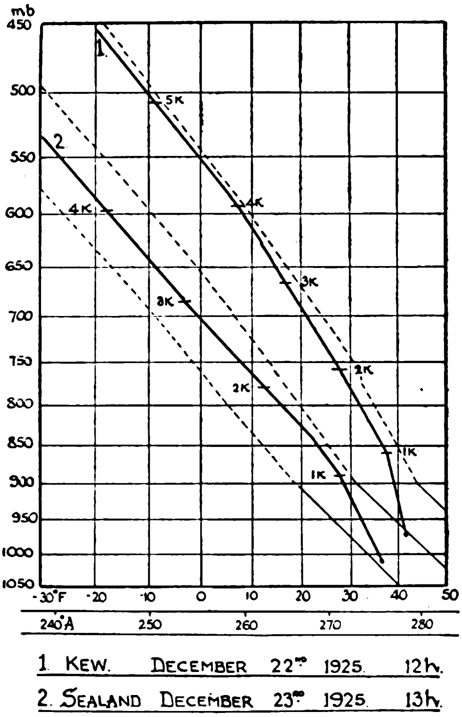

FIG. 5.—(For explanation see Fig. 3).

Other examples of sounding balloon ascents during frontal rain were made at Pyrton Hill on November 3, 1910, and on September 13, 1911; at Farnborough on January 30, 1913; at Eskdalemuir on May 9, 1913; at Sealand on November 11, 1924, and on April 14 and October 15, 1925. An inversion occurred on October 15, 1925, and some very small inversions on January 30, 1913, but as a rule the fronts were shown by layers of reduced lapse rate.

2.2 The second curve on Fig. 3, and those on Figs. 6 and 7, are based on aeroplane observations at Duxford (near Cambridge), in the main rain areas of important depressions. In the first case, that of July 31, 1925 (Fig. 3), the clouds during the descent, when the rain had started, were in a continuous layer down to a low level. In the case of September 22, 1925, at the beginning of the rain, the nimbus and alto-stratus layers were still separated, but in the other cases the clouds were continuous above the levels marked as "cloud base," and in all cases the clouds extended beyond the highest level attained. These unbroken masses of cloud are characteristic of continuous precipitation. The low turbulent nimbus is largely due to eddy motion in air made damp by falling rain; it merges up into the alto-stratus which constitutes the real rain-cloud, though near the front this rain-producing cloud itself extends to a low level, and is apt to be turbulent.

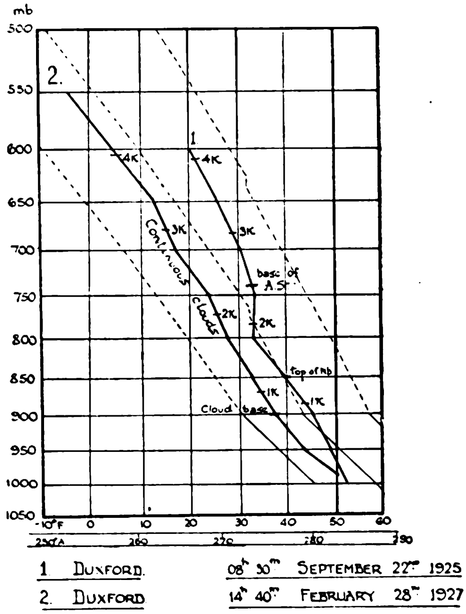

FIG. 6.—Upper air observations in continuous rain. Clouds extending beyond the highest level reached. (For further explanation see Fig. 3).

The inclusion of the "saturated adiabatic" lines provides the best method of estimating the magnitude of the discontinuity. The rising warm air presumably follows a saturated adiabatic line, and the normal lapse rate in both the warm and the cold air masses above 1 or 2 kilometres is near the saturated adiabatic rate. If, therefore, we start at the top of a smoothed discontinuity, say, for example, at 650 mb. pressure on curve 1 of Fig. 7, and follow down the appropriate saturated adiabatic line to the base of the discontinuity, say at about 780 mb., we obtain the total magnitude of the discontinuity, in this case about 9°F. In these cases the discontinuities were rather small, and the horizontal temperature differences, deduced from changes in 24 hours, were much the same. Larger discontinuities are quite common, especially in late autumn and winter. A case such as that in Figs. 4 and 5 suggests that there are often important horizontal temperature gradients outside the transitional zone which corresponds to the smoothed sloping surface of discontinuity.

2.3 The following are some additional notes on the examples in the diagrams:—

July 31, 1925.—A depression with a warm sector was moving eastward up the English Channel. The front was 190 km. from Duxford. The diagram shows a smooth discontinuity at a height of about 3 to 4 km.

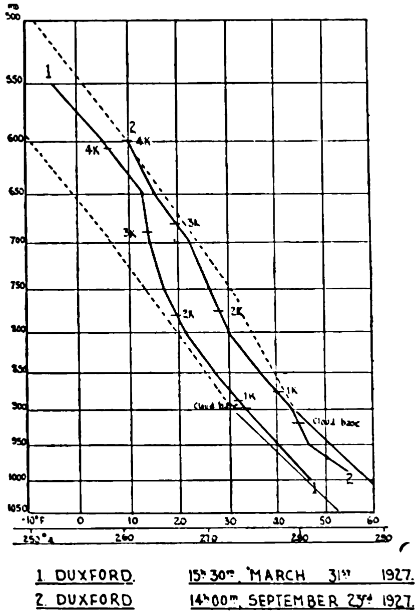

FIG. 7.—Further upper air observations during rain, with unbroken clouds above the levels marked as "cloud base." (For further explanation see Fig. 3).

September 22, 1925.—A very deep depression off south-west Ireland was moving north-east; it was occluded at the centre but had a warm sector further to the south-east. The warm front was 270 km. from Duxford. The diagram shows an isothermal patch at a height of about 2 km.

February 28, 1927.—A very deep occluded depression over southern Ireland was moving north-east. The original warm sector was apparently occluded 24 hours previously, but the depression continued to deepen, attaining its maximum depth at 13h. on February 28. No evidence of air from the original warm sector is shown in the Duxford ascent. Neither the upper air nor the surface temperatures show any real discontinuity at all. It was really a case of continuous motion, the rain area being due to convergence into the isallobaric "low" (*i.e.*, the area of rapidly falling pressure).[4]

March 31, 1927.—An intense depression, recently occluded and at its maximum depth, was moving east-south-east over southern England; it passed well to southward of Duxford, the occlusion being 240 km. away. The curve shows a smooth discontinuity at about 3 km.

September 23, 1927.—An intense depression over the western part of English Channel, just occluded but still deepening, was moving north-east. The occlusion was about 260 km. away, and there was a very smooth discontinuity at a height of about 1.8 to 2.8 km. (It must be remembered that in the case of an occlusion the angle of the slope cannot be calculated from the height and the distance away of the discontinuity, since the warm front does not cut the ground.)

Other ascents on March 23 and 29 and April 11, 1927, and on July 3, 1928, reveal similar features to those shown in the diagrams.

2.4 The distinction between the cyclonic and the thundery type of rainfall is well known, but there are intermediate cases, and also cases when irregular showery or thundery rains amalgamate into continuous rain areas. One would expect this to happen where there is convergence combined with an unstable lapse rate for saturated air. Numerous and extensive "anvils," spreading from cumulo-nimbus clouds, form clouds of alto-stratus type, and may ultimately amalgamate into a continuous mass. A sounding balloon observation in the rain area of a secondary depression formed in polar air was made at Sealand at 8h. on May 7, 1926, and revealed a lapse rate exactly equal to the saturated adiabatic from 1 to 4 km. By 13h., when surface pressure was at its lowest, temperature from the surface to 4 km. had risen slightly, but at 18h., in rear of the secondary, temperature had fallen at all heights. If such a rain area developed in an extensive region with a lapse rate above the saturated adiabatic, the air over the rain area would become warmer up above than the adjacent air. A depression formed in these conditions might resemble a tropical cyclone, though on a much feebler scale (*c.f.* paragraph 3.5). Probably more frequently there is an intermediate type of depression, in the development of which both vertical instability and horizontal temperature differences play their part.

2.5 When a Bjerknes depression is occluded there is a single rain belt, with polar air on both sides of it but relatively warm air above it, associated with some sort of trough of low pressure. When such troughs and rain belts appear on a synoptic chart they are commonly called "occlusions," whether or not there is any real evidence that the warm sector ever existed. My own opinion is that on some occasions the rain develops along a single belt as the result of convergence due to the isallobaric "low" and to surface friction. For example, on November 10, 1926, a deep depression formed at a cold front in the polar air off western Ireland, and this front swept round, passing as a northward-moving trough across the British Isles, with a rain area in front of it.

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[4] See Brunt and Douglas, *loc. cit.*

About a week later, on November 16 to 18, a depression moved from southern Greenland to southern Ireland, growing deeper although surrounded with polar air, and during the process quite a sharp front developed, with a rain area in front of it. A method of development of such a front in a depression has been given by T. Kobayasi.[5] It must, however, be remembered that the depressions which develop in polar air are only a minority, and that in most cases the front exists before the depression, and developments proceed along more or less orthodox lines.

3. The Structure of Depressions.

3.1 The example in Figs. 4 and 5 confirms my former conclusion that the statistical results for the three-dimensional structure of depressions do not apply to soundings made in equatorial air (or through a front up into equatorial air). Comparing the observations on December 22 and 23, 1925, we find that while surface pressure was 30 mb. lower on the former date, the pressure at 9 km. was 9 mb. higher, and that the base of the stratosphere was 2.7 km. higher. A series of aeroplane observations on November 2 to 4, 1925, was in some respects even more illuminating. A sounding in the warm sector near the centre showed a temperature at a height of 4.6 km. about 23°F. warmer than in the polar air in front of and behind the system. At the earth's surface the movement of the depression caused a brisk fall of 12 mb. in the barometer, followed by an equivalent recovery; while at the 4 km. level the barometer remained practically steady, and above that level there was a wedge of high pressure in place of the depression. As a depression deepens, the barometer falls over the warm sector, especially near the centre, the warm sector being occluded by the end of that time. The structure shown in Fig. 4, with low barometric readings but still a good deal of warm air, is comparatively rare. The structure of depressions is so variable that one is forced to the conclusion that the only feature which they all have in common is a centre of low pressure on the surface chart, with a corresponding wind circulation.

3.2 Now in the warm sector the horizontal temperature gradient is not generally steep, so that the possibility of a fall of pressure resulting from the drawing in of still warmer air masses is distinctly limited. A more probable explanation of the falling pressure is the presence of an advectional effect higher up, with air spreading over at high levels, bringing with it lower pressure and temperature in the troposphere and a lower and warmer stratosphere, properties which are possessed by air originating in higher latitudes. In the case of November 2 to 4, 1925, when the pressure at the centre of the depression only dropped by 8 mb. as it moved from south-east England to Denmark, the development would have involved merely a flattening out of the wedge of high pressure which existed at high levels. In the case of most large and deep depressions there is probably a spreading of real polar air right over the system during its rapid deepening, simultaneously with the diminution and final disappearance of the warm sector. Some such process is indicated by the known statistical facts regarding upper air conditions over depressions. The spreading in of the polar air at great heights was shown in an interesting diagram published by L. H. G. Dines,[6] giving isopleths of upper air temperature for the period April 14-16, 1925. On the evening of April 14 the warm sector had just been occluded and the sounding, made in the rain band of the occlusion, showed a smoothed front with a small lapse rate from 0.5 to 2 km. Since the morning the temperature had risen up to a level of 4 km., and fallen at greater heights, and the height of the tropopause had decreased. Next day, in typical showery, " polar-air " weather, temperature had fallen considerably throughout the troposphere, and the stratosphere was very low.

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[5] *Q.J.R. Meteor. Soc.*, **50**, 1924, pp. 339-363.

It is well known that a pronounced polar current behind a depression greatly favours its deepening. Marked cyclonic development sometimes takes place at a straight front running from south to north, but very rarely at a straight front running from west to east. There is a tendency for the westerly component of wind velocity to increase upwards, to some extent independently of fronts, so that there is a better chance of the polar air over-running at great heights when the alignment of the front is from south to north.

3.3 An additional argument for this over-running process is deducible from a consideration of angular momentum. D. Brunt[7] has shown that increasing cyclonic circulation implies convergence to an axis, so that when a depression deepens the required withdrawal of air takes place right above it. This is not a theory but the statement of a mathematical identity with which all theories must comply. In the case of a depression developing on the polar front, the region of very strong cirrus motion is on the polar side of the front (see Fig. 8), at the top of the smoothed sloping surface of discontinuity. There appears to be no possibility of a supply of cyclonic angular momentum being available in the upper currents immediately over the developing cyclone, so that all theories depending on the direct withdrawal of air across cylindrical walls (for example, enclosing and travelling along with a vortex in a general " solid " current) can be rejected. The only possible alternative is an advectional theory, in which an already existing " high depression " (not necessarily closed at the centre) comes in over the top of the developing depression shown on the surface chart. In the same way the development of an anticyclone involves

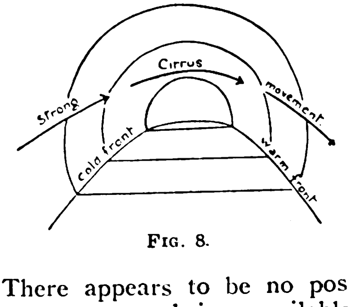

FIG. 8.

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[6] *Meteor. Mag., London*, **61**, 1926, p. 69.
[7] *Proc. R. Soc.*, **105** (A), 1924, pp. 70-80.

the arrival of a "high anticyclone," consisting of tropical air, over the subsiding polar air.

These ideas are, of course, not new, and have in particular been supported by various German writers.[8] Since, however, there is still so much divergence of opinion on these questions, it seems worth while to set out the above arguments, which seem to me very difficult to answer. It does not follow that the high-level depression is of more importance than the warm sector. Personally, I attach more importance to the warm sector, which supplies the depression with energy during its displacement by the polar air. It need hardly be added that the prospects of a complete theory of depressions are still remote. A possible key to the ultimate solution of the problem lies in the curious anomaly that whereas the fall of pressure during the development depends on air movements at high levels, the requisite supply of energy is found mainly in the lower layers.

3.4 The upper cold depression may be in the nature of a vortex travelling in the general current in the manner described by Sir Napier Shaw.[9] It must, however, be remembered that in the earlier stage of the life history of a depression, the centre (or trough) of the upper depression lies altogether outside the system shown on the surface chart. Any idea that a depression with a genuine warm sector has a symmetrical vortex above it has never been supported by even a single example.

3.5 It may perhaps be objected that in the case of tropical cyclones there is little or no possibility of a high depression spreading in above. But it is reasonably certain that during the development of a tropical cyclone, a column of warm air is built up. Sir Napier Shaw[10] has given figures comparing the normal upper temperatures in the tropics with those assumed by saturated air rising adiabatically from the surface; a column of this saturated air would be so much warmer than its environment that a corresponding cyclone with readings as low as 930 mb. at the centre would disappear at a height of 15 km., near the top of the troposphere. It can easily be shown that a cyclone with readings of 960 mb. at the centre would only extend up to about 9 km., and would be relatively feeble even at 6 km. Angular momentum equal in magnitude to that represented by the cyclone, but of opposite sign, must be distributed in the upper atmosphere, probably over a considerable area. The three-dimensional structure of a typical depression of temperate latitudes must be fundamentally different from that of a tropical cyclone, though in the case of a depression formed entirely in polar air there may be some resemblance.

4. THE EFFECT OF SUBSIDENCE.

4.1 The dynamical warming of descending dry air is an old principle in meteorology, and it can now be placed on a rough quantitative basis. The process we are considering is the gradual sinking of the overlying air which inevitably accompanies divergence in the horizontal wind circulation in the lower part of the atmosphere. It is, of course, an entirely different process from the local downward currents of small-scale convection which are shown in double-theodolite pilot-balloon ascents. The relationship may be easily expressed mathematically. Let us consider a circular cylinder of air resting on the ground, of height h and radius r, and let v be the radial component of wind velocity, considered positive for an outward movement, w be the vertical velocity, and ρ the density. Then from the equation of continuity (neglecting $\partial\rho/\partial t$), we have

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[8] See e.g. G. Stüve. "Der Zusammenhang zwischen der oberen und der unteren Druckwelle." *Beitr. Physik. Atmosph., Leipzig*, **1**, 13.

[9] Manual of Meteorology (Camb. Univ. Press), Part IV. (1919 Edition). Ch. X. See also appendix at the end of this paper.

[10] *London, Meteor. Office, Geo. Mem.* No. 19 (M.O. 220 i.) Introduction See table on p. 220.

$$2\pi r h \overline{\rho v} = -\pi r^2 \, [\rho w] \quad . \quad . \quad . \quad (1)$$

where the bar denotes an average taken over the walls of the cylinder, and the squared brackets an average taken over the top of the cylinder. A system of geostrophic winds gives no appreciable divergence, so that we need only consider the deviations from the geostrophic winds. It has been shown by Brunt and Douglas that, with certain qualifications, there is divergence from an isallobaric high, the amount of which can be calculated from the gradient of isallobars. There is also divergence along a ridge between two isallobaric lows, or round the edge of a pronounced isallobaric low surrounded by a region with relatively small pressure changes. When there is a very pronounced isallobaric high behind a fast-moving depression, the problem is complicated by other terms in the equations of motion, and the real divergence is normally less than that calculated directly from the isallobars.[11] Taking this into account, we find that divergence over a considerable area rarely exceeds 2 or 3 m/s. When an anticyclone is developing, the barometric rise takes place over a considerable area, and the gradient of isallobars is weak, so that the divergence from a mass of air, followed along its mean motion, is usually rather less than 1 m/s. if averaged over 24 hours. It is an observed fact that during the development of an anticyclone the pressure in the upper air rises with the surface pressure, so that in equation (1) we may take v as roughly constant from 600 m. up to 3 or 4 km. or more. On some occasions v may even increase with height. The process we are discussing obviously involves a building up of the anticyclone at high levels, and we have seen that this is probably brought about by the arrival of cold tropical air in the stratosphere.

When we assume v to be constant we may write equation (1) (ignoring the very small variation of ρ over the top of the cylinder, and calling its mean value ρ_1) in the form

$$[w] = -\frac{2h\overline{\rho v}}{r\rho_1} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Taking $v = 1$ m/s., $r = 400$ km., $h = 3$ km., and $\overline{\rho}/\rho_1 = 1.2$, we have $[w] = .018$ m/s., *i.e.*, 65 metres per hour, or about 1.6 km. per day. The average value over most developing anticyclones is probably usually less than this, but is at least of the order of a kilometre per day at the 3-km. level. From equation (2) we see that w increases numerically with h, and since with a normal initial lapse rate the warming at a fixed level depends on the amount of downward motion, the lapse rate is decreased by the subsidence.

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[11] See Appendix at the end of this paper.

4.2 In an unchanging stationary anticyclone the only divergence and subsidence is that due to surface friction and is quite small. Sir Napier Shaw[12] calculated that in a large high-pressure area with light winds the subsidence is as small as 80 m. per day. Assuming no divergence or convergence at greater heights, the downward velocity above about 600 m. is inversely proportional to the density, but its increase with height and the resulting stabilising effect is quite small. It is when an anticyclone is developing that the large subsidence and marked stabilisation take place. The relative humidity above an anticyclonic inversion (say at 1.5 km.) is usually below 30 per cent and sometimes below 10 per cent. If the air were just saturated when it started to descend, a relative humidity of 25 per cent at 1.5 km. would imply a descent of rather more than 2 km., while a figure of 10 per cent would indicate a descent of nearly 3.5 km., which, with a normal lapse rate and adiabatic conditions, would cause a rise of temperature of about 25°F. at the level to which the air descended. Occasionally, though rarely, humidities of about 1 per cent are observed, indicating descent from about the top of the troposphere. The Norwegian meteorologists have shown that in a developing anticyclone the lower air is of polar origin, and when the anticyclone becomes a stationary " warm " one, there is no indication that the air in the central area is changed.

4.3 The inversions are not confined to anticyclones but may occur in any mass of air subsiding under the specified conditions. They are now often called " surfaces of subsidence," though the term is a little misleading, as it suggests a surface of separation between air which is subsiding and air which is not subsiding, whereas it is much more probable that the discontinuity is developed within a subsiding mass of air. The clearest statement with regard to their probable method of formation was that given by M. A. Giblett[13] in discussing the aeroplane observations at Cranwell on October 19, 1923, when there was an inversion in the polar air behind a cold front, the equatorial air being found at higher levels, with no inversion at the boundary surface. After referring to the work of Margules and Exner on the stabilising effect of subsidence, Mr. Giblett wrote as follows:—" But in passing over a relatively warm surface, such as the Atlantic, the cold air mass would receive heat from below and this would be diffused upwards as far as the turbulence originating at the surface is able to penetrate in the face of the stabilising action of the sinking."

This question is worth considering in greater detail. The tops of the cumulo-nimbus clouds in a deep polar current may reach the base of the stratosphere, but as soon as subsidence starts they tend to spread out at a definite level, say 3 km. It was shown many years ago by Sir Napier Shaw[14] that when a mass of air containing a cloud sheet subsides, stability is increased at the upper surface of the cloud but decreased at its lower surface. The latter effect would tend to maintain the convection and therefore the cloud sheet, if enough moisture were carried up to counteract the effect of the general slow subsidence. As an example, suppose that the top of the clouds was originally at 3 km. with temperature 20°F. and pressure 700 mb., and no inversion. If the clouds descended adiabatically to 1.5 km. and were still maintained in a continuous layer, the temperature in the cloud would be 37°F., and in the dry air above it would be 48°F. forming an inversion of 11°F. If the clouds were only a broken layer, the inversion would be smaller. The observed relationship between clouds and inversions is close, and although an inversion may exist without clouds there is no evidence that it can be initially developed in cloudless air. Once an inversion has formed, it may persist for some time after its original causes have ceased to act.

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[12] The Air and its Ways (Camb. Univ. Press), 1923.
[13] *Nature, London*, **112**, 1923, p. 863.
[14] Forecasting Weather (Constable and Co.), 1911 Edition, p. 172.

4.4 It is important to know to what extent clouds can be maintained in subsiding air. In the case given above, when the saturated air was warmed from 20° to 37°F., while descending from 3 to 1.5 km., an amount of 2.2 grammes of water per kilogramme of air would have to be added to maintain the amount of condensed water unchanged. If the water evaporated meanwhile from the sea surface were evenly diffused by turbulence up to a level of 1.5 km., the total required would be a layer of water 4 mm. thick. Now a computation by M. A. Giblett,[15] under conditions appropriate to this problem, showed that the air after traversing 1,000 km. of sea surface at a velocity of 5 m/s., or in a time of about 55 hours, would have gained by evaporation water vapour equivalent to a layer of water 4 mm. thick. With stronger winds and greater turbulence the period required would be less. A descent of 1.5 km. in 55 hours represents a fairly slow rate of subsidence, but it is with slow subsidence that cloud sheets and large inversions are met. If there is a very strongly marked isallobaric high, there is usually very little cloud and only a small inversion, if any, though the lapse rate up above becomes stable. It is probable that some of the smaller inversions, up to about 5° or 6°F., are developed in periods of the order of 24 hours or less, though it is impossible to prove this without observations from a network of stations. Such a development would correspond to the figures given in the preceding paragraphs, with a diverging component of 1 m/s., a descent from 3 to 1½ km., and with the layer under the inversion about half clouded during its descent.

4.5 It has also been suggested that the inversions may be caused by turbulence carrying heat downwards from underneath them. The downward conduction of heat by turbulence requires that the lapse rate should be initially stable and that the turbulence should be of mechanical and not of thermal origin. These conditions are frequent near the ground, and may obtain higher up when there is an abnormally rapid change of wind in relation to height. In the case of the typical inversions above the lowest kilometre, the strong wind shearing is above the base of the inversion, while the turbulence is below that level, with a lapse rate up to the adiabatic, so that there is no conclusive evidence that this process is of much importance in these cases. On the other hand, there can be little doubt that radiation is important in increasing a discontinuity already formed.

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[15] *Proc. R. Soc.*, **99** (A), 1921, pp. 472-490.

4.6 If subsiding air is cooled at the surface, as over the Continent in winter, there is a large inversion near the ground, and stable conditions up to 2 or 3 km. If subsiding air is rapidly heated at the surface, but little moisture is added, as over the Continent in summer, there is hot, cloudless weather with an adiabatic lapse rate during the day up 1.5 km. or so, and stable conditions in the layer above, but inversions are relatively small and scarce. The scarcity of inversions above the lowest kilometre or so in South-Easterly currents over or near the British Isles supplies evidence that the addition of both heat and moisture at the surface is usually required to develop inversions at these higher levels. At Berck in 1918-19, out of 220 inversions observed above 1.2 km., only 12 occurred with winds in the SE. quadrant, compared with 100 with winds in the NW. quadrant. An additional cause may be that a moving anticyclone takes in air in front of it and leaves air behind in its rear, so that the air has subsided for a longer period when the wind is in the SE. quadrant, and the inversions tend to be lower.

4.7 [Note added January 3rd, 1929:—Since writing the preceding paragraphs I have discussed the whole question of the "dry inversions" with Mr. M. A. Giblett. We are agreed that the primary cause is subsidence, combined with turbulence up to a definite limit. The details of the physical processes vary considerably, and it is thought that there are five factors to be taken into account, some or all of which may act simultaneously in varying degrees. They are as follows:—

(*a*) Turbulence of mechanical origin.
(*b*) Turbulence mainly of thermal origin, with rising currents carried by their momentum slightly above their equilibrium position.
(*c*) The different rates of warming of cloudy and of dry air during subsidence.
(*d*) Horizontal movements bringing colder air below warm, dry air.
(*e*) Radiation.

Mr. Giblett calls attention to some observations made in Egypt when factor (*b*) appears to predominate, since, even with dry, solid currents from the desert, inversions of a few degrees are sometimes found just above the limit of convection at about 2 km. The protrusion of the tops of cumulus through strato-cumulus clouds into an inversion shows that this factor operates to some extent in our own area.

In connection with (*a*) Mr. Giblett referred to the observations of H. U. Sverdrup[16] in Arctic regions, which showed that with strong winds a positive lapse rate extended to about 200 metres, with an inversion above.

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[16] *Washington, U.S. Dep. Agric. Monthly Weath. Rev.*, **53**, 1925, pp. 471-475.

The importance of factor (*c*) in our own area has already been urged. Extensive masses of strato-cumulus cloud are found below fully 90 per cent of the inversions between 1 and 3 km., but in some of these cases the other factors, notably (*b*), are probably predominant, as for example, with Easterly winds crossing the North Sea in winter.

Factor (*d*) is thought to be usually subsidiary in character, its effect being chiefly to intensify already existing inversions in certain cases. When the inversion has a slight slope the resulting wind discontinuity may increase the inversion if the temperature gradient is suitable.

With so many factors acting it is evident that no final conclusions can be reached till more observations are available.]

4.8 When the warm, dry air is near the ground, turbulence penetrates it whenever there is much wind, or when heat is being added at the earth's surface. This is the only means by which any of the subsiding air can reach the ground, where the vertical velocity is obviously zero. The effect of surface heating on temperature is greatly increased by subsidence, since the convective region through which the heat is distributed becomes a relatively thin layer.

4.9 The ordinary anticyclonic inversion is usually horizontal, but some "dry inversions," notably those associated with fronts, but occurring some distance below the true frontal surfaces, have a definite angle of slope, usually less than 1 in 200. It is to these sloping surfaces that the term "surface of subsidence" is most often applied, but there is no evidence that there is always, or even normally, downward sliding on the surface itself. Since these inversions are similar as regards temperature and humidity to those in anticyclones, it is reasonable to suppose that their origin is also similar. It appears, however, that there must be a zone of divergence in the polar air near the sloping frontal surface, of which no adequate explanation is at present forthcoming.

The atmospheric structure revealed over Cranwell on October 19, 1923, proved to be quite a common one. Some good examples over Brussels have been published by J. Jaumotte.[17] The characteristic feature is a "dry inversion," or at least a dry layer not penetrated by turbulence, with the true frontal discontinuity above, marked chiefly by a large rise of humidity (usually with alto-stratus clouds) and sometimes also by a small temperature inversion. The best Brussels case, that of July 2, 1924, was reproduced in an article by E. V. Newnham,[18] and the diagram showing temperature, humidity, and cloud structure in relation to height may profitably be compared with the diagrams in this paper, showing the great difference made by considerable amounts of precipitation. The precipitation makes the humidity high at all levels, so that if there is descending air it is evidently kept practically saturated by evaporation from the drops (or snowflakes) and is warmed at the saturated instead of at the dry adiabatic rate; this prevents any dynamical warming at a fixed height if the lapse rate is normal. If a layer of air has previously been warmed adiabatically and is therefore dry, the precipitation falling through it would cool it decidedly. Evidence for this precipitation effect can be obtained from autographic records at the surface, one good example having been discussed by the present writer.[19] If this reasoning is correct, it follows that the source of energy of the type required for Margules's well known scheme is to be sought more especially in the precipitation area,[20] since outside that area the dynamical warming of the polar air by descent smooths out the discontinuity over a zone often hundreds of kilometres in width.

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[17] *Ciel et Terre, Bruxelles*, **43**, 1927, pp. 31-36 and 49-54.

[18] *Meteor. Mag., London*, **63**, 1928, pp. 6-8.

5. Wind Discontinuities.

5.1 To a first approximation the wind in the upper air is geostrophic, and its change with height is controlled by the horizontal temperature gradients, which are conspicuously high at a sloping surface of discontinuity. The vector change of wind experienced while passing upwards through such a discontinuity is parallel to the front, and for an observer with his back to this vector wind the warm air is on the right hand side. Some good examples of wind discontinuities have been observed by pilot balloons, all associated with fronts. This agrees well with theory, but, as invariably happens in meteorology, further investigation has shown that the problem is far more complex than it appeared to be at first. In this case the complication is the " surface of subsidence," discussed in the preceding section.

Let V be wind velocity, considered as a vector, and h the height. In many cases when the surface wind direction is reversed aloft, we find that the vector $\partial V/\partial h$ is fairly constant, and such cases are not discontinuities. There is no rigid definition of a discontinuity, and there must always be marginal cases, but a study of pilot balloon observations suggests two main types of wind discontinuity. The first is characterised by outstandingly high values of $\partial V/\partial h$ through a definite layer, occasionally as thin as 300 metres; the second by a sudden jump of $\partial V/\partial h$ from a low to a high value, which it maintains fairly constantly through a large range of height, the wind up at cirrus levels being exceedingly strong, often exceeding 60 m/s. in winter. This type of wind structure contains a discontinuity in $\partial V/\partial h$ rather than in V. There are also discontinuities of intermediate type. The best examples of wind discontinuities observed by pilot balloons in the British Isles since 1920 are as follows:—

February 14, 1920, Eskdalemuir (two ascents).
April 28, 1920, South Farnborough.
January 27, 1921, South Farnborough.
November 2, 1921, Eskalemuir (2), Renfrew, Leuchars.
September 21, 1922, Leuchars.
November 3, 1922, Cranwell.
October 19-20, 1923, Cranwell (3), Calshot.
April 13, 1924, Calshot.
April 15, 1924, Holyhead, Shotwick.
April 23, 1925, Holyhead.
October 16, 1926, Croydon.
April 29, 1927, Holyhead.
December 19, 1927, Biggin Hill.
December 20, 1927, Biggin Hill.
July 3, 1928, Lympne.
August 3, 1928, Upper Heyford (Oxfordshire).

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[19] *Q.J.R. Meteor. Soc.*, **54**, 1925, pp. 19-25.

[20] A high concentration of potential energy in the precipitation areas was shown up by T. Bergeron and G. Swoboda in their discussion and diagrams on pp. 150-152 of their paper " Wellen und Wirbel im einer quasistationären Grenzfläche über Europa. (Leipzig, 1924)

Full details of the above cases may be found in the Upper Air Supplement of the *Daily Weather Report* of the Meteorological Office. The list is fairly complete as regards the really pronounced discontinuities associated with well marked fronts. The sharpest discontinuity was that over Eskdalemuir at 8h. on February 14, 1920, when the wind increased from 14 to 27 m/s. between heights of 2.7 and 3.0 km. In the summer months the fronts on the surface chart are not so pronounced as at other seasons; the last two cases are included so as to represent summer conditions, and no doubt others of similar type were observed in previous summers, though that of August 3, 1928, seems to be unusually sharp. There can be no doubt that shell bursts provide a more effective method than pilot balloons of observing wind discontinuities. At Berck in the spring of 1919, 7 cases of marked wind discontinuity, all associated with fronts, were observed in a period of 4 weeks, and in most of these cases the wind was so strong that a pilot balloon would have been blown out of sight before it reached the discontinuity at all. The probability of the balloon being lost at the discontinuity itself is also considerable. In order to investigate a wind discontinuity in any detail by means of shell bursts, an additional expenditure of ammunition would be necessary.

5.2 Among the examples given in the above list, observations of upper air temperature in the vicinity were available on eight occasions, and in every case there was either an inversion or layer of reduced lapse rate corresponding with the wind discontinuity. It is a useful working rule that a layer where the rate of wind shearing ($\partial V/\partial h$) is exceptionally large, whatever the direction of the vector $\partial V/\partial h$, is almost sure to be a layer of small lapse rate. In order to distinguish between a surface of subsidence and a true frontal surface, one requires observations of humidity as well as of temperature. If there is a very low humidity a surface of subsidence is indicated. With temperatures below freezing point, wet bulb readings usually give humidities too high, though never too low. In order to be certain that the air is damp one must either have a record from a reliable hair hygrograph, or else the wet bulb must be kept properly wet. New methods of achieving this have recently been introduced, so that before long it may be possible to identify cases of wind discontinuity at a frontal surface proper. Among the eight cases mentioned above, four were doubtful and four were surfaces of subsidence. For two of the latter, those of November 2, 1921,[21] and October 19-20, 1923, a number of pilot balloon ascents are available and the angle of slope can be roughly determined. In the first case it was about 1 in 150, and in the second case less than 1 in 200. One of the cases with no temperature observation, that of April 14, 1924, at Calshot, is of interest in that the warm front rain of an active depression followed about 3½ hours later. At the time of observation (11h.) the front was about 500 km. away. There was a pronounced wind discontinuity at a height of between 3 and 3½ km., and cirro-stratus above, no doubt much higher up, which indicates that the wind discontinuity was probably a surface of subsidence. If the true frontal surface has lost most of its wind discontinuity it can no longer be of much dynamical importance. This adds emphasis to the suggestion in the preceding section that it is in the rain area that there is the greatest release of kinetic energy in developing depressions.

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[21] For further details of this case, together with a synoptic chart, see Brunt and Douglas, *loc. cit.*

6. TURBULENCE AT SURFACES OF DISCONTINUITY.

6.1 The question of the amount of turbulence at a surface of discontinuity has considerable interest. It was shown in Appendix 2 of the *Memoir* by Brunt and Douglas that if there is much turbulence at a smooth sloping surface of discontinuity the resulting deviation of the wind from its geostrophic value may have an appreciable effect on the rainfall. Direct measurements of the turbulence are quite impossible at present, but some light may be thrown on the subject by means of a criterion due to L. F. Richardson,[22] who showed that in dry air turbulence tends to increase if

$$\left(\frac{\partial V_x}{\partial h}\right)^2 + \left(\frac{\partial V_y}{\partial h}\right)^2 > \frac{g}{\theta}\left(\frac{\partial \theta}{\partial h} + \frac{g}{\gamma_p}\right)$$

where V_x, V_y are the components of the mean wind velocity V, g is the acceleration due to gravity, θ the absolute temperature, h the height, and γ_p is the specific heat of air at constant pressure. In deriving the formula, the turbulence is assumed to be independent of height. The "dry adiabatic" lapse rate is of course equal to $-g/\gamma_p$, and if $\partial\theta/\partial h$ equals this value turbulence always tends to increase. The author[23] has already used this criterion to show that for a given angle of slope too sharp an inversion becomes unstable. The reason for this is that when there is a sloping discontinuity the vector $\partial V/\partial h$, which is squared on the left hand side of Richardson's criterion, is roughly proportional to the amount by which the lapse rate in the discontinuity differs from the lapse rate in the air underneath. An inversion of 3°C. in 100 metres is fairly sharp but not abnormally so, and the corresponding limiting angle is 1 in 300, the value of the vector being then about 3.7 m/s. per 100 metres (27 m.p.h. per 1,000 feet). In the list of extreme cases given in the preceding section, this figure was only once reached,[24] and we may conclude that it is very rare indeed. The fact is that almost all sharp inversions are practically horizontal.

6.2 In normal conditions at heights above a kilometre the right hand side of Richardson's expression is decidedly the larger. In really interesting cases the two sides are more nearly equal, and an accurate comparison would require synchronous observations of upper winds and temperature at the same place, with self-recording instruments, preferably including two self-recording theodolites. Actually none of these conditions are fulfilled, but nevertheless it is perhaps worth while to make a few comparisons. Observations of wind and temperature at the same place are only available for two cases, both surfaces of subsidence, as follows:—

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[22] *Proc. R. Soc.*, **97** (A), 1920, pp. 354-373.

[23] *Q.J.R. Meteor. Soc.*, **50**, 1924, Appendix, p. 359.

[24] The pilot balloons were observed at height intervals of 500 feet, roughly 150 metres.

Place and date.	Approx. height	$\left(\frac{\delta V_x}{\delta h}\right)^2 + \left(\frac{\delta V_y}{\delta h}\right)^2$	$\frac{g}{\theta}\left(\frac{\delta\theta}{\delta h} + \frac{g}{\gamma_p}\right)$
	km.	sec.$^{-2}$.	sec.$^{-2}$.
Leuchars, Nov. 2, 1921	1.9	5.8×10^{-4}	6.1×10^{-4}
Cranwell, Oct 19, 1923	1.6	3.5×10^{-4}	3.9×10^{-4}

In these cases stability was maintained by a small margin. In the Cranwell case the humidity fell off so quickly with height in the inversion that there cannot have been appreciable turbulence. In some other cases observations were available at places some distance apart, but within 100 km. of each other, and the figures are at least worth mentioning. In some of these cases the heights are not quite the same, owing to the slope of the surface of discontinuity.

Date.	Place of pilot balloon.	Approx height	$\left(\frac{\delta V_x}{\delta h}\right)^2 + \left(\frac{\delta V_y}{\delta h}\right)^2$	Place of upper air temp.	Approx. height	$\frac{g}{\theta}\left(\frac{\delta\theta}{\delta h} + \frac{g}{\gamma_p}\right)$
		km.	sec.$^{-2}$.		km.	sec.$^{-2}$.
April 28, 1920	S. Farnboro'	3.8	9.5×10^{-4}	Andover	4.4	5.9×10^{-4}
Oct. 16, 1926	Croydon	2.0	5.4×10^{-4}	Duxford	2.5	2.4×10^{-4}
Dec. 19, 1927	Biggin Hill	4.3	2.3×10^{-4}	S. Farn.	4.3	3.7×10^{-4}
Dec. 20, 1927	Biggin Hill	2.1	2.3×10^{-4}	Duxford	2.7	3.5×10^{-4}
Aug. 3, 1928	Upper Heyford	1.7	7.0×10^{-4}	Duxford	1.7	4.2×10^{-4}

On December 20, 1927, hygrograph readings in Holland indicated a surface of subsidence. In three cases the left hand term was the greater, indicating unstable conditions. It must, however, be remembered that the sharpness and magnitude of inversions vary greatly from place to place, and may even change considerably during an aeroplane flight. Such local variations are usually associated with variations in the character of cloud sheets. In the case of August 3, 1928, pilot balloons at other stations did not show so sharp a discontinuity. The first Duxford ascent was made at 8h., two hours later than the Upper Heyford pilot balloon, and showed dry air above the inversion. The second ascent was made at 15h., and showed low humidities from 300 metres up to the base of the inversion, which was at the same level as before, but larger in magnitude, amounting to 6°F. From about the middle of the inversion to above the highest level reached (3.7 km.) there was a continuous layer of alto-stratus cloud. Local rain was then already falling in southern England, and heavy general rain fell early next morning. The whole problem is very complex and the observational material is very inadequate.

6.3 In the cloudy air of rainy "fronts" upper wind observations are of course altogether lacking, but the problem may be approached theoretically, assuming "geostrophic" motion. The table given in the appendix of my earlier paper,[25] giving the limiting angles of slope for various lapse rates in the sloping layer of discontinuity, can be modified so as to refer to saturated air.

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[25] *loc cit.*

During rain the cloud layer is continuous, and when there is turbulence we may regard both the rising and descending portions of the eddies as containing cloud particles. In Richardson's criterion we may substitute on the right hand side the expression

$$\frac{g}{\theta}\left(\frac{\delta\theta}{\delta h}+\beta\right)$$

where β is the appropriate "saturated adiabatic" lapse rate. (In effect one is using a fictitious perfect gas with such specific heats that it behaves like saturated air over a certain limited range of pressure. The method is accurate enough for practical purposes.) We shall take a sloping discontinuity with a lapse rate within it below the saturated adiabatic and a lapse rate below it equal to the saturated adiabatic, say 6°C. per kilometre. Assuming geostrophic motion the angle α is the limiting angle of slope of the discontinuity consistent with stability

	Inversions.						
$\frac{\delta\theta}{\delta h}$ in discontinuity (°C per km.) -	+10	+5	+2	0	−2	−3	−4
tan α - - -	.005	.006	.007	.008	.010	.011	.014

(The above figures are practically the same as those for dry air in my previous paper. They are not, however, directly comparable, as in that paper the lapse rate below the discontinuity was taken as 7°C. per km. If we subtract one all along the top line, the lower line gives the limiting angle with a lapse rate below the discontinuity of 7°C. per km. and a similar value of the saturated adiabatic rate, which at a pressure of 750 mb. implies a temperature as low as 260 a. The lapse rate below the inversion is of course not necessarily equal to the saturated adiabatic. A table like the above could be made for any values.)

It is known from actual observations that the angle frequently exceeds 1 in 100, so that turbulence in the discontinuity will increase unless the lapse rate in the discontinuity is not much less than the saturated adiabatic. This is probably the reason why the frontal surface is usually smoothed out unless the angle is very small. We cannot, however, estimate the amount of turbulence, and we do not know whether a discontinuity would become sharp even in the absence of turbulence. Ordinary sharp inversions are developed by a fundamentally different process. Towards the centres of rapidly deepening depressions, where the fronts tend to be rather steeply inclined, it is quite likely that the coefficient of eddy diffusivity may rise as high as 5×10^4 cm.^{2} sec.$^{-1}$, which would cause important deviations from geostrophic winds.[26]

6.4 Layers of alto-cumulus clouds are associated with turbulence within and just under them. Sometimes there is a "dry inversion" above them, indicating subsidence, but a high lapse rate below them; the turbulence is probably due to this, any abnormal rate of wind shearing that exists being above the clouds.

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[26] See Brunt and Douglas, *loc. cit.*

not in or below them. On other occasions there are no inversions (or at most very small ones), but one or more layers of alto-cumulus form in a damp layer of considerable thickness, with a comparatively small lapse rate. The alto-cumulus is often a degenerate form of alto-stratus when no precipitation is falling, and it is probable that wind shearing associated with the smoothed frontal surface sets up the turbulence required. It must, however, be kept in mind that the turbulence in the course of time modifies the distribution of temperature and of wind. As with most problems in meteorology, various factors are hopelessly mixed up, and cause and effect cannot be distinguished. Radiation certainly ought not to be neglected.

7. OVER-RUNNING FRONTS.

7.1 It is now known that a cold front often arrives at a height of 600 metres or so before it arrives at the ground, an effect obviously due to surface friction. In a case analysed by M. A. Giblett,[27] the tip of the cold wedge at 600 metres is shown about 6 km. in advance of the front at the surface. In cases when the wind in the cold current increases with height (strictly speaking—the wind component at right angles to the front) there would be a tendency for over-running to take place at greater heights also. A smoothed sloping surface of discontinuity with the cold air above, with a lapse equal to the dry adiabatic in the transitional layer, represents a theoretical possibility which has never been actually observed. Probably the formation of clouds brings the lapse rate below the adiabatic and smooths the discontinuity still further. It seems probable that over-running of cold air at high levels should be interpreted in terms of continuous rather than of discontinuous motion. The over-running is certainly of importance in connection with thunderstorms, and it has been shown that it is probably also an important factor in the deepening of depressions.

As a rule the temperature at 4 km. in shallow thundery depressions drops only a few degrees, and sometimes not even that, before the front arrives at the ground, and a larger fall occurs some time afterwards, as the cold current extends upwards. The fall of temperature high up is probably continuous, a little of it being of the nature of over-running, but more of it of the nature of under-running of the cold air. More pronounced over-running appears to have taken place in a fairly deep depression on September 22, 1927. An observation was made at Duxford at 14h. on that day, barely 100 km. behind a cold front, and the temperature had fallen decidedly at all heights since the previous day, the fall amounting to 14°F. at 550 mb. pressure (about 4.7 km. height). Most of this fall must have taken place in advance of the front. Anything in the nature of a vertical front with a narrow transitional zone is quite impossible. If one had a calm at the earth's surface, a cirrus velocity of 60 m/s. (134 m.p.h.) would be very strong, and would be rarely exceeded. Such a velocity at a height of 8 km. means a pressure gradient of about 3.4 mb. per

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[27] *J. R. Aero. Soc.*, **31**, 198, 1927, pp. 509-549.

100 km., and if there is no gradient at the surface this implies that the mean temperature of the column of air up to 8 km. has a gradient of about 2.4°C. (4.3°F.) per 100 km. Now with such high cirrus velocities the total temperature difference between the cold and warm air masses is likely to be fully 10°C. (18°F.), so that the transitional zone would be 400 km. (250 miles) in width. Whether expressions such as "front" or "discontinuity" are appropriate to such cases is a matter for discussion; I suggest that the latter term at least is inappropriate. A belt 250 miles in width is not large on the scale of a modern synoptic chart, but it cannot be accurately represented by a chalk line, which is the usual method of marking fronts. From the above reasoning we may conclude that a change from a sloping surface of discontinuity with the warm air above to one with the cold air above could not take place without very thorough mixing.

7.2 The rain frequently observed in advance of a cold front has not yet been adequately explained. A study of the changes of the pressure gradients close to the front fails to show why convergence should take place in advance of the front, instead of at the frontal surface itself, which would give rain through the cold air. It is tempting to suppose that a wedge of cold air with its tip at (say) 2-km. height lifts the overlying warm air. This idea not only lacks direct confirmation (which in any case would be very difficult to get) but cannot be reconciled with the rapid fall of the barometer which is normally in progress. A rapid fall of pressure often accompanies the spreading over of polar air at great heights, but there seems little reason to suppose that the effect of a wedge of cold air at 2 km. would differ from that of a wedge at the surface, which always causes a marked diminution of the fall of the barometer, if not an actual rise. The question must be left for further research.

A closely analogous problem is that of the "trigger" action connected with thunderstorms in advance of a cold front. A very good case of this occurred in the early morning of July 5, 1927, when there was a very general outbreak of thunderstorms about 300 km. in advance of a well marked cold front. At London (Kingsway) the barometer rose 0.5 mb. with the storm, probably owing to the cooling effect of the rain (though this did not show at the surface), and, behind it, fell 2 mb. in 20 minutes. The sharp cold front passed six hours later without thunderstorms. An aeroplane ascent at Duxford soon after the storm showed unusually high temperatures at levels of 1 to 2 km., conditions being stable from 0.3 to 1.5 km., but unstable for saturated air high up. Some kind of trigger action was necessary to start off the disturbance.

APPENDIX (ADDED NOVEMBER 8, 1928).

Note on the Combination of Steady Rotary and Translatory Motions.

In the third section of this paper it is argued that when a depression is deepening there must normally be an over-running high-level depression, cold in the upper part of the troposphere.

Now with geostrophic wind velocities the arrival of cold air involves a wind which backs with increasing height. In the case of cold air over-running a warm sector, usually with SW. winds, this wind structure is improbable, and it is much more likely that the upper wind has a component across the isobars at its level, blowing outward in front of the advancing depression. It will be shown that this component is present when any unchanging circular rotating wind system in steady motion is superimposed on and carried along by a uniform current of air, a type of motion which will be referred to in future as "simple transport."

In a previous discussion[28] of this over-running cold air, I pointed out that the required outward component certainly exists in the case of Sir Napier Shaw's travelling cyclone of constant vorticity, rotating like a solid. As a rule the vorticity decreases as the radius increases, and in the combined motion the isobars are crowded together on the right hand side of the travelling system, but are widely spaced on the left hand side, where they are not always closed at all. This type of motion is certainly characteristic of high levels. Now D. Brunt[29] has shown that to any system of velocities which satisfy the general equations of motion there may be added a uniform velocity of translation U, provided that the pressure distribution is corrected by the addition of a gradient $l\rho U$ at right angles to U (where ρ is the density and $l = 2\omega \sin\phi$, ω being the angular velocity of the earth's rotation and ϕ the latitude). Our proposition follows at once from this. The following form of proof, which is simpler than the one I originally produced, is due to Mr. Brunt.

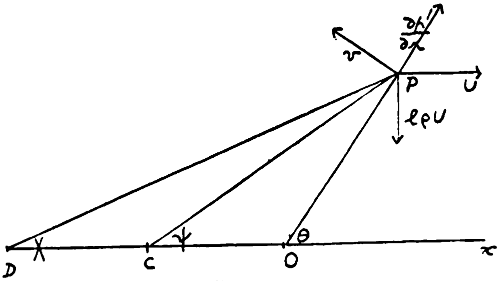

FIG. 9.

Let O be the centre of the revolving system, which does *not* coincide with the centre of any isobar of the combined system. The velocity of travel U is in direction Ox. At any point P the components of pressure gradient consist of $l\rho U$ at right angles to Ox and $\partial p'/\partial r$ along OP, where OP$=r$ and p' is the pressure corresponding with the rotary field only. The components of wind velocity are U along Ox and v at right angles to OP. Let PD and PC be perpendicular respectively to the wind velocity and the isobars of the combined field, and denote the angles POx, PCx and PDx by θ, ψ, χ, respectively. The following relations hold:—

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[28] *Mem. R. Meteor. Soc.*, **1**, 1927, No. 7.

[29] *Proc. R. Soc.*, **99** (A), 1921, pp. 397-402.

$$\tan\chi = \frac{v\sin\theta - U}{v\cos\theta} = \tan\theta - \frac{\rho lU}{\rho lv\cos\theta} \quad . \quad . \quad . \quad (1)$$

$$\tan\psi = \tan\theta - \frac{\rho lU}{\dfrac{\partial p'}{\partial r}\cos\theta} \quad . \quad . \quad . \quad . \quad (2)$$

$$\frac{\partial p'}{\partial r} = \rho lv + \rho\frac{v^2}{r} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Substituting (3) in (2) and comparing with (1), we see that when $\cos\theta$ is positive, $\tan\psi > \tan\chi$, or $\psi > \chi$. From this it follows at once that the component of motion across the resultant isobars is outward in the front half of the depression and inwards in the rear half. By reversing the sign of v and $\partial p'/\partial r$ we get the same result for a travelling anticyclone.

The combination of rotary and translatory motions has applications to conditions at 600 metres as well to greater altitudes. When two fields of motion, both without convergence or divergence, are superimposed in this way, it is evident that the combined field has also no convergence or divergence, although there must in general be closed groups of isallobars due to the movement of the system. In order to compute the convergence or divergence from the isallobars, one should first attempt to estimate the effect of this "simple transport" and eliminate it from the isallobaric field. In the case of some secondaries the element of simple transport is evidently large, but with quite a number of moving depressions it is small or even zero, as far as the layers near the earth's surface are concerned, as may be shown from a vector analysis of the isobaric field. The movement has then the character of a development in front and a dissolution in the rear, a process which is often complex. Sometimes a new centre develops in front and the old one fills up, often swinging round as a dying secondary to the new centre. More frequently a development of this type is shown up only by bulges on the isobars. The frequency of these complex movements is known only to habitual students of six-hourly weather maps. Similar principles hold in the case of moving anticyclones or wedges.

DISCUSSION.

Sir **RICHARD GREGORY**: Mr. Douglas has covered a very wide field in his paper and has suggested many topics for discussion. The relations between movements of air at high levels and near the surface are associated with many problems of prime importance, and such a collection of observations and influences as is embodied in this comprehensive contribution to meteorological knowledge is both instructive and enlightening. I am sure that several Fellows will wish to express their views upon Mr. Douglas's conclusions, and will join with me in congratulating him upon a stimulating paper.

Lieut.-Colonel **GOLD** (*communicated*): In reading this paper I was struck by the way in which the pictorial appeal of Fig. 1 is marred by the artificial breaks in the rainfall record. The diagram would make a much more telling appeal to the ordinary reader if these breaks were eliminated and the continuous record shown. I have myself sinned by this slavish adherence to the instrumental record, but I never realised its defects so clearly before. I was specially interested in the third of the points of Mr. Douglas's summary, and his reference to the rôle of advection in the production of depressions and anticyclones. In the report of Dr. Harwood and myself to the British Association in 1909 we pointed out the important consequence of the lower temperatures of the equatorial stratosphere in these words: "this will result in enroachments of the equatorial cold air on the advective region [stratosphere] of temperate latitudes and such encroachments will produce anticyclonic regions." The idea was developed further in *Geophysical Memoirs* No. 5, where it was shown that the encroachments could be in the form of waves, either standing waves corresponding with permanent stationary anticyclones or travelling waves corresponding with moving anticyclones. I had not thought it likely that the converse process would be responsible for our deep revolving depression. These are more confined to the troposphere than anticyclones which stretch up well into the stratosphere [depressions may, in fact, as Mr. Douglas points out, not even extend to the top of the troposphere]. I had therefore considered depressions as probably tropospheric in origin, arising partly as phenomena in the currents of the general circulation and partly from the condensation of water vapour and the consequent thermal changes and discontinuities. It will be interesting if, in fact, depressions prove to be due to encroachments of polar air in the neighbourhood of the 9-kilometre level —a level made for ever prominent in upper-air research by the work of W. H. Dines.

Mr. J. S. Dines said that he wished to offer a few remarks on the structure of depressions, the subject dealt with in the first part of Mr. Douglas's paper. When it was shown a good many years ago that the old view which regarded a depression as a warm column of ascending air was not tenable, Mr. W. H. Dines formed the opinion from his upper-air observations that the proper place to look for the cause of a depression was at the base of the stratosphere. This theory was unfortunately one which forecasters were unable to use in their daily work, as observations to this great height are not obtainable by aeroplanes but only by sounding-balloon ascents, the records from which are received much too late to be of use in forecasting. Then the Bjerknes polar front theory came along. This in its initial stages was built up almost entirely on surface observations, and could therefore readily be applied in forecasting; it has been given close consideration and received a wide degree of acceptance. The theory may usefully be divided into two parts (1) that which concerns the formation and growth of a depression and (2) that which concerns the formation of rain. The first part (1) states that depressions form on the polar front and that their growth is dependent upon their having a warm sector, ceasing a short time after their occlusion. The second part of the theory (2) associates nearly all rainfall with warm and cold fronts. The present speaker thought there were few people working constantly with synoptic charts who would doubt the association of rain with fronts and who would not be prepared to accept this part of the Bjerknes theory as one which was likely to form a permanent contribution to meteorological science, but when it came to the formation and growth of depressions he was not sure that the position was quite so satisfactory. It was impossible to overlook the fact that there were occasions when large temperature contrasts failed to be associated with any special activity in the growth of depressions and other cases when a depression which had lost its warm sector seemed to be capable of much further growth. He thought Mr. Douglas inclined to the view that there were two types of depression, one which formed entirely in polar air and was probably similar to the tropical cyclone in its structure and another which formed on the polar front. This might be so, but it seemed doubtful whether depressions could permanently be separated into two distinct classes in this way. Might it not be that in the same way as Einstein was reported to have abandoned his relativity theory in favour of a new generalization because while relativity explained the gravitational field it did not explain electro-magnetic phenomena, so meteorologists might have to abandon existing theories on the formation of depressions in order to find some new theory which would embrace all cyclonic systems? If such a new theory should place the seat of action at the base of the stratosphere it would be a remarkable testimony to the foresight of Mr. W. H. Dines.

Mr. D. BRUNT welcomed Mr. Douglas's paper, particularly in that it emphasised the importance of convergence, and stressed the fact that depressions have only one feature in common, namely a centre of low pressure. The latter fact made it impossible to draw one plan and to say that it represented the cyclone of middle latitudes. He felt that fruitful research into such problems as were treated in Mr. Douglas's paper could only be carried out by those in daily contact with synoptic charts.

Sir GILBERT WALKER welcomed the idea that the fall of pressure in the warm sector must be due to the spreading over of air from higher latitudes, and asked what was the reply to the objection that, as Hesselberg had shown, the motion of cirrus cloud was not in general from the north but in the direction of motion of the cyclone, usually slightly north of east. He pointed out that mere descent in a mass of air would, as Exner pointed out, have but a small diminishing effect on the vertical temperature gradient in the mass itself, though turbulence within the mass would raise the temperature at the base and so tend to develop an inversion between the air there and that immediately below: so inversion would weaken at night and strengthen as the sun's heat made itself felt. Perhaps this formed a partial solution of the problem why the moon is said to "eat up" the clouds. He welcomed also the idea that rainfall usually formed in sheet clouds and that nimbus clouds were frequently mere products of turbulence in the very damp air below; for it was more in accordance with ordinary ideas that rain at a warm front should form in the climbing warm air and not in the colder air below the inversion.

Mr. W. H. PICK said he felt that Sir Gilbert Walker's stated belief, based largely on Hesselberg's work, in the idea that the direction of movement of the centre of a depression was invariably coincident with that of the cirrus clouds preceding the depression was not justified. He said this with the more confidence because of some recent work done by Mr. D. F. Bowering and himself, the details of which have recently been published[30] in the Society's *Quarterly Journal*. In that work the movements of the centres of all depressions occurring on or near the western borders of the British Isles within a certain period of time had been compared with the movements of their preceding cirrus clouds as shown by nephoscope observations at Holyhead and Sealand (near Chester). The results could be briefly stated. For the direction of the movement of centres of primary depressions the direction of the cirrus movement furnished only a poor guide. For the direction of the movement of centres of secondary depressions the direction of the cirrus movement furnished a much better guide without anything like complete concurrence being found. The velocity of movement of the preceding cirrus seemed to have little or no relation to the velocity of movement of the depressional centres no matter whether primaries or secondaries were considered. These results, it will be seen, do not support those obtained by Hesselberg, and the discrepancy calls for further work to be done on the subject. Mr. Bowering and he were hoping to pursue the matter in a further statistical note to the one already referred to, and it is to be wished that others will take up the subject, as it is an important one from the viewpoint of practical forecasting.

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[30] Vol. **55**, p. 71, 1929.

Mr. C. K. M. Douglas said in reply to Mr. Dines that he certainly thought that the depressions which develop in polar air were different from those formed on the polar front, though there were also intermediate types. In fact, as was stated at the end of paragraph 31, the only feature which all depressions have in common is a centre of low pressure, the three-dimensional structure being subject to great variation. In reply to Sir Gilbert Walker's first point, he thought that the air from higher latitudes probably spreads over a depression from the rear, after following a curved path. The scheme outlined in the appendix made the over-running process depend on a small component of motion across the isobars at the level in question, a much larger component being along the isobars, which were nearly parallel to the isotherms. This scheme fitted in with the observed facts of cirrus motion. On the question of subsidence, the argument in paragraph 4.1 depends on a downward motion increasing with the height, a process which certainly decreases the lapse rate. While there could be no question that turbulence and cloudiness have a marked diurnal variation over land, no adequate data as to the corresponding effect on inversions seem yet available. Turbulence *above* the inversion is negligible.

(Note added March 6). In case my reply to Mr. Dines may seem to imply an attitude of pure pessimism, perhaps I may be allowed to add a few remarks to indicate that the situation may not be entirely without hope. The great achievement of the Bergen meteorologists was their discovery that the life history of a depression consists essentially of a transition from asymmetry to symmetry, and it is quite probable that all depressions go through an evolution of this type. When a depression deepens after occlusion it is probable that symmetry has not been attained, even though conditions at the earth's surface appear symmetrical. It is in the conditions of growth and decay that some factor common to all depressions is most likely to be found. Upper air research should concentrate on this problem, which requires a *series* of observations at fairly short intervals from a network of stations, on occasions selected by a competent authority a few hours in advance, and broadcast by wireless. It seems essential that Margules's energy relationships should be extended so as to be made applicable to depressions in which advection plays an important rôle. The difficulties are very great, but I suggest that the problem should be tackled by someone with the necessary ability. If a Bjerknes warm sector is represented by a field of isotherms, it is evident that the field can, roughly speaking, be resolved into a linear field, together with a field giving a warm core to the depression. During subsequent developments the warm core is replaced by a cold one, and the linear field is also frequently destroyed. In the case of a depression forming in polar air, it is argued in this paper that a warm core is developed, and in most cases there is also a linear field, though weaker than in the true Bjerknes depression. Thus we have something resembling a warm sector, though often not well defined, and this is subsequently removed. There is, however, one important difference between the two classes of depression. Whereas in the true Bjerknes depression the warm sector owes its warmth and moisture to advection, in the polar-air depression the warmth and moisture are derived from the sea in a relatively short period of time and are carried up by convection in unstable air, with condensation. Thus the warm sector is intensified during the first stage of the growth of the polar-air depression, the warming up above being helped by the convergence. This additional factor would have to be taken into account in a treatment of depressions based on the supply of energy.

Thomas Gray Memorial Trust.

Under the will of the late Thomas N. Gray, the Royal Society of Arts is residuary legatee of his estate for the purpose of founding a memorial to his father, the late Thomas Gray, C.B., for many years Assistant Secretary to the Board of Trade (Marine Department). The objects of the Trust are " the advancement of the science of navigation and the scientific and educational interests of the British Mercantile Marine."

The Council of the Society is now offering a prize for an essay on the following subject :—

> " You are overtaken by a revolving storm. Discuss the handling of a low-powered steamer from the time of the first indication of the approach of the storm until the storm has passed, supposing the ship to be in (*a*) the safe semi-circle, (*b*) the dangerous semi-circle, and (*c*) the direct path of the storm's centre."

The essays must be sent in under a motto, accompanied by a sealed envelope enclosing the author's name, which must on no account be written on the essay. A breach of this regulation will result in disqualification.

Judges will be appointed by the Council, which reserves the right of withholding the prize or awarding a smaller prize if, in the opinion of the judges, no suitable essay is submitted. The Council also reserves an option on the copyright of the successful essay.

Essays must be sent not later than December 31, 1929, to the Secretary, Royal Society of Arts, John Street, Adelphi, London, W.C.2.

Royal Observatory, Greenwich, Report to the Council of the Royal Meteorological Society of Observations during the Year 1928. (Communicated by the Astronomer Royal).

Meteorological observations have been continued on the lines followed in previous years.

During the year 1928 the *temperature* of the air varied between 92.0°F. on July 22 and 23.9°F. on December 15. 80° was exceeded on 18 days, on two of which 90° was also exceeded. Temperatures of 32° and lower were recorded on 34 days, including one in October when a minimum of 29.3° was reached on the unusually early date of October 14.

The mean temperature for the year was 50.6°F., 1.1° above the average for the 75 years 1841-1915. No less than four months had a mean temperature approximately 3½° in excess of the normal. These were January, February, July and November.

The highest reading of the *solar radiation* thermometer *in vacuo* was 164.1°F. on July 22. This day also provided the greatest range between maximum and minimum readings of the radiation thermometers, namely 126.6°. On 59 days a range of more than 100° occurred. The minimum temperature on the ground during the year was 13.9° (on December 9).

The total number of hours of *bright sunshine* registered during the year was 1603.4, or 36 per cent. of the possible amount. This is a marked improvement over recent years; and the months of July and September were sunnier than in any year since 1911. Eleven days had upwards of 90 per cent. of the total possible. Four of these were consecutive days in July, July 12 culminating with 15.3 hours or 94 per cent. There were 68 entirely sunless days in the year.

The proportion of hours of clear sky at night as indicated by the night-sky recorder reached 45 per cent. of the whole time of exposure (*i.e.*, of 3438 hours), and represented, like the total sunshine, an increase of almost exactly 33 per cent. on the previous year's total.

The total *rainfall* in the year was 25.25 inches, *i.e.*, 1.0 inch above the 75 years' average. September was the driest month of the year, with 0.69 inch, in contrast to the previous year, when it was the wettest. October was the wettest month in 1928, with 3.45 inches. Maximum rainfall occurred on June 14, 1.09 inches being registered on that day, and on August 4 the total was within one hundredth of reaching the inch mark. From July 10 to 26 there was a period of 17 consecutive days without measurable rain. Rain fell on 177 days in the year.

Wind. The total horizontal movement of the air, as given by the Robinson anemometer, was 109252 miles during the year. On February 11 the total for the day was 1003 miles, the greatest yet recorded at Greenwich. The maximum movement in any hour of the year occurred on November 16, when 58 miles was registered during the 18th hour. A pressure of 47.0 lbs. to the square foot occurred during the same gale. This had not been equalled since April, 1882.

Summarising the general character of the year's weather, a mild winter and rather late spring were followed by a summer fine above the average, though not exceptionally warm. Except for a short cold spell in December, the end of the year was reached without serious frost.

THE RATE OF ASCENT OF PILOT BALLOONS AT MELBOURNE.

By E. KIDSON, O.B.E., D.Sc., F.Inst.P., and H. M. TRELOAR, B.Sc.

[MS. received in revised form June 20, 1928—Read February 20, 1929.]

1.—INTRODUCTION.

Since the beginning of 1922 pilot balloons have been observed at Melbourne by means of a single theodolite and a Barr and Stroud range-finder with a base of 80 cm. So long as the balloon is in range, therefore, its true height can be determined. The maximum distance observed with the range-finder is 5,000 yards, but the accuracy is not very great beyond 3,000 yards. In the observations discussed in this paper balloons were filled to ascend at a rate of 100 metres in 45 seconds according to J. S. Dines's formula:—

$$V = q\frac{L^{\frac{1}{2}}}{(W+L)^{\frac{1}{3}}}$$

in which q was given the value 84. The balloon is observed at the instants at which, according to the formula, it should have reached the heights of 100, 200, 300, 400, 500, 700, 900, 1,100, etc., metres. The range is frequently too short for the range-finder at the first reading which is consequently missed. There is no indication, however, that the results obtained for the height at the first reading are not fairly representative. At greater heights there are frequent interruptions owing to the presence of cloud, but it is considered that until the fifth reading is reached the data are representative of all conditions. For the later readings the balloon will be out of range for strong winds and loss of record owing to cloud will occur in a considerable proportion of the ascents. The mean results, therefore, are believed to be quite reliable up to the fifth reading, but much less so beyond that.

It has been remarked that our diagrams suggest the possibility that the range-finder is consistently inaccurate at short ranges. The theory and construction of the range-finder and the practical demands which it has to satisfy make it at least very unlikely that such would be the case when ranging on fixed objects. Nor do we think that the argument can be sustained on the evidence of our diagrams. The instrument was frequently tested by taking a series of five readings of the range of a flagstaff at a measured distance of 2,680 yards and adjusted to read correctly at this distance. Occasionally it was tested, also, on the limb of the moon. The great majority of the observations were made by ourselves, and as each shared fairly equally in the making of the tests, any personal equation should be eliminated in the mean of a long series. The balloon was always observed at the same spot in the centre of the field. It would be difficult to imagine a mean instrumental error of one per cent. at 2,680 yards. The error should be proportionally smaller at shorter distances. Although the setting of the range-finder has to be altered rapidly when the balloon is at short range we feel confident that this can be done with the necessary accuracy. Shortly after the range-finder was procured it was used during a number of two-theodolite ascents, the base being the above-mentioned 2,680 yards. The range-finder observations were made by several observers, none of whom had at that time had much experience with the instrument. Table I. gives a comparison of the balloon heights as determined from the range-finder and the two theodolites respectively. The difference in altitude between the two stations was 30 metres. The nearness to this true value of the observed difference between the heights of the balloon above the respective stations (called z in column 1 of Table I.) gives some measure of the accuracy of the two-theodolite observations.

TABLE I.—COMPARISON OF BALLOON HEIGHTS AS DETERMINED BY THE RANGE-FINDER AND BY TWO THEODOLITES.

z	First Reading.					Second Reading.				
	No. of Obs.	Theod. – Range-finder.				No. of Obs.	Theod. – Range-finder.			
		Algebraic Mean.	Numerical Mean.	Max.			Algebraic Mean.	Numerical Mean.	Max.	
m.		m.	m.	m.	%		m.	m.	m.	%
27–33	13	+1.5	4.5	+10	7	14	– 1.0	7.8	–29	15
23–26 34–37	11	–0.1	1.9	– 6	6	11	– 1.1	8.0	–32	12
23–37	24	+0.8	3.3			25	– 1.1	7.9		
<23 >37	8	+4.9	11.3	+27	21	14	–10.0	12.5	–76	33

The results are grouped according to the deviations of z from its true value, the limits being given in the first column. Except when the theodolite readings are inaccurate, the average differences between the balloon heights as determined by the two methods are small. Where the differences are large they are, in the majority of cases, consistent with the view that the error is in the theodolite readings. The range-finder heights gave the more uniform velocities. The range-finder was adopted at Melbourne because of the conviction after experience that it gave more accurate results for short ranges and under all conditions than any of the other methods.

In a preliminary investigation by one of us (H.M.T.) of the heights at the fifth reading during the years 1922-1924, results similar to those of Moltchanoff[1] were found independently. Since neither the type of balloon nor the theoretical rate of ascent was uniform in 1922 and 1923, the following discussion is confined to ascents observed between January, 1924, and June, 1927, although the previous years' results are in accordance with the conclusions reached. The balloons generally weigh between 8 and 12 grammes and the free lift is, therefore, in the neighbourhood of 30 grammes.

From 1922 to 1924, inclusive, observations were made at 09.30, 11.00 and 15.30 hours on all weekdays except Saturday, when there was no afternoon observation. Subsequently the 11.00 hour observation was discontinued.

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[1] Moltchanoff, P. Ascensional Rate of Pilot Balloons from Observations at Pavlovsk, Russia. Abstract by W. C. Haines in *Washington, D.C., Mon. Weath. Rev.*, **54**, 1926, p. 8.

2.—The General Wind Regime.

In order that the situation may be appreciated, some knowledge of the wind régime at Melbourne is necessary. This may be gathered from Figure 1, which was prepared for another purpose and

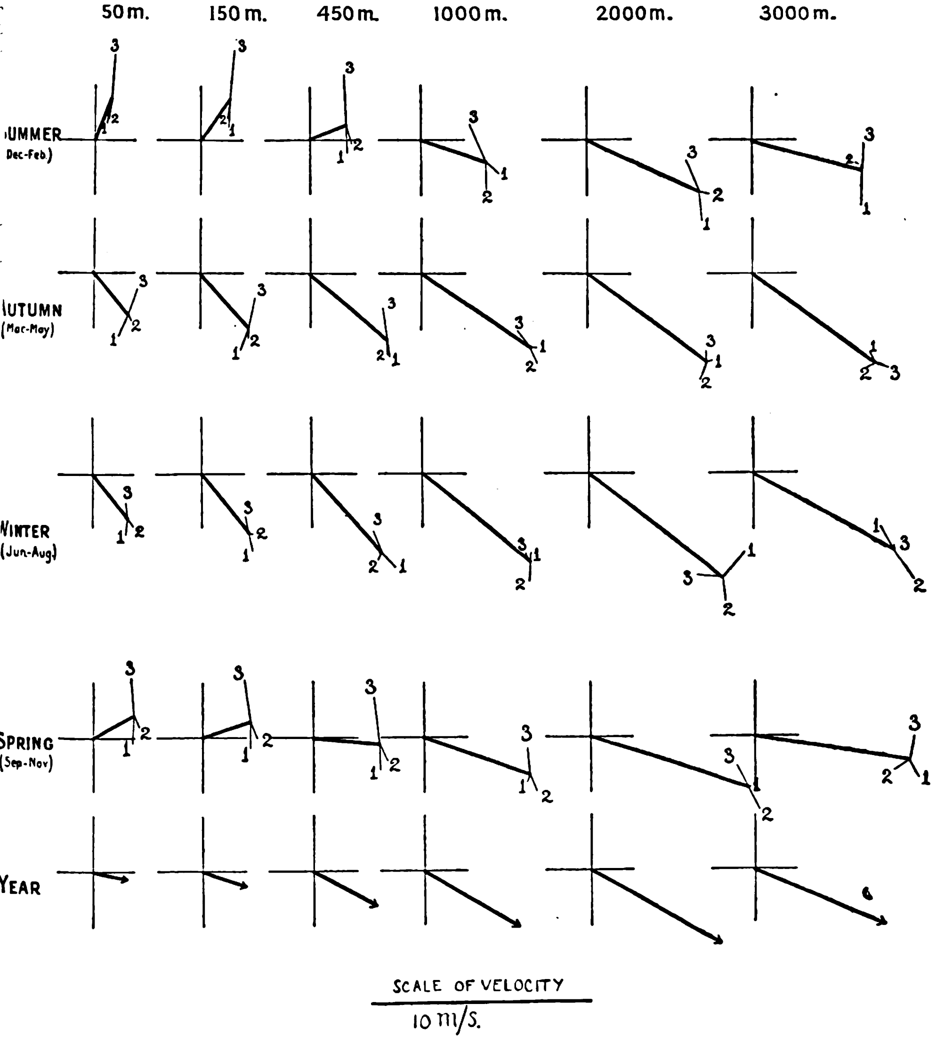

Fig. 1.—Diurnal and annual variation of wind at various heights (3 years' observations). The principal vector is the mean wind. The smaller vectors at the end of the large one show departures from the mean at (1) 09.30h., (2) 11.00h. and (3) 15.30h. Vectors are drawn from the centre with the wind.

which is based on the observations during 1922, 1923 and 1924. The figure shows the resultant mean wind for four seasons and for the year as derived from the three daily observations. These values are shown by the thick line in each diagram. In addition, the smaller vectors shown by the thin lines give for each season the departure at each of the times of ascent from the mean of all three. Some idea can be gathered, therefore, of both the diurnal and the annual variations. Data are given for heights of 50, 150, 450, 1,000 2,000 and 3,000 metres. The results up to 2,000 metres are believed to represent average conditions. Beyond that there is some selection owing to the balloon being lost in distance or cloud in certain types of weather before 3,000 metres is reached.

The outstanding feature is the prevalence of North-Westerly winds. A fairly strong Westerly component was to be expected in the latitude of Melbourne, but so persistent and large a movement from the N. is remarkable. At 1,000 metres there is a resultant Northerly component at all seasons. Cloud and balloon observations indicate that this drift is maintained up to cirrus level although at that height, perhaps, it is less marked that at middle altitudes. The drift from the N. appears to be characteristic of Australia and is, doubtless, a function of its relation to the general distribution of land and water over the globe.

3.—MEAN HEIGHTS.

The mean heights at the readings when according to the formula the balloon should have been at 100, 200, 500, 900 and 1,100 metres were computed for each month and each time of observation from all the observations. The height is so variable that three and a half years is not nearly sufficient to give normal monthly means. The values plotted in Fig. 2 are smoothed means according to the formula $\frac{a+b+c}{3}$. Even with these there is considerable irregularity and only the more salient features can be relied on. The vertical scale of the lowest curve is four times, and of the second curve double that of the upper curves.

The first point to notice is that the balloon is very high at the first reading throughout the year. It is still high at the second reading, but in the autumn and winter months the excess is less than at the first reading. At the fifth reading, although the mean height for the year is still above the computed height, in the autumn and winter months the reverse is the case. At the higher levels the balloon is considerably below the computed height. The number of readings at these levels is rather small and the conditions are probably to some extent selective, but it is unlikely that the figures give a very wrong impression.

Fig. 3 gives the mean rates of ascent up to the ninth reading corresponding to the heights in Fig. 2. The rates for the ninth to eleventh readings are omitted for simplicity, owing to their irregularity and great range. It will be seen that between the first and second readings, though the mean rate of ascent is still above that calculated, it is below it from April to August. At greater heights, in the mean for the day, the rate is always below that calculated.

4.—THE ANNUAL VARIATION.

The principal feature of the annual variation is that the heights are lower in winter than in summer. There are irregularities at the later readings, but up to the fifth the curves suggest a sine curve

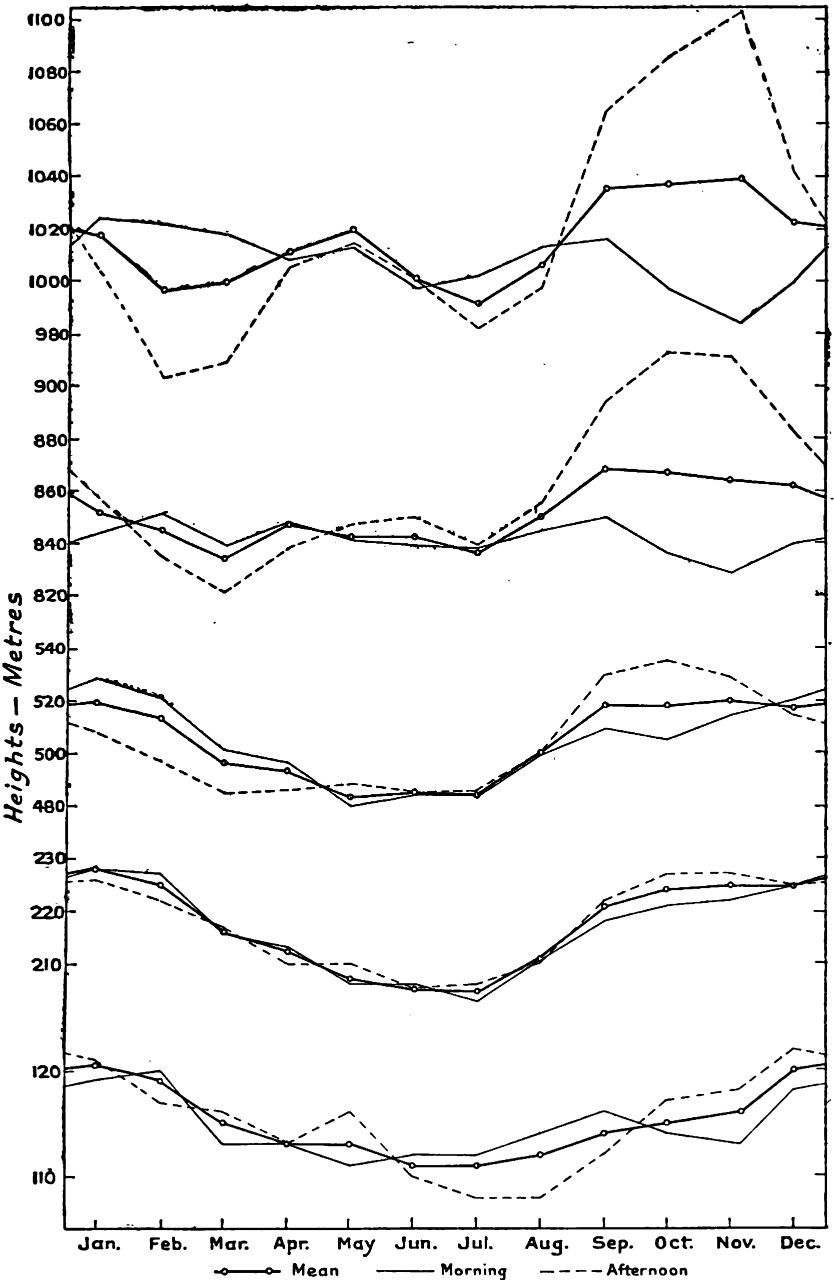

FIG. 2.—Annual Variation of Mean Height of Balloon. Mean Monthly values, smoothed according to formula $\frac{a+b+c}{3}$, of the heights at the first, second, fifth, ninth and eleventh readings. [The computed heights at these readings are 100, 200, 500, 900 and 1100 m. respectively.]

in phase with the sun's motion in declination. The most marked departure is in spring when the heights are too great. It is believed that this excess is due to actual ascending currents in the air which is being heated by the land at that season. The effect is very clearly shown in the afternoon ascents at all heights. It is not nearly so marked at the morning ascent and is, in fact, reversed at the greater heights. The mean for the day was obtained by weighting all observations equally and since there are more in the morning than in the afternoon, the former have a greater influence in determining the mean.

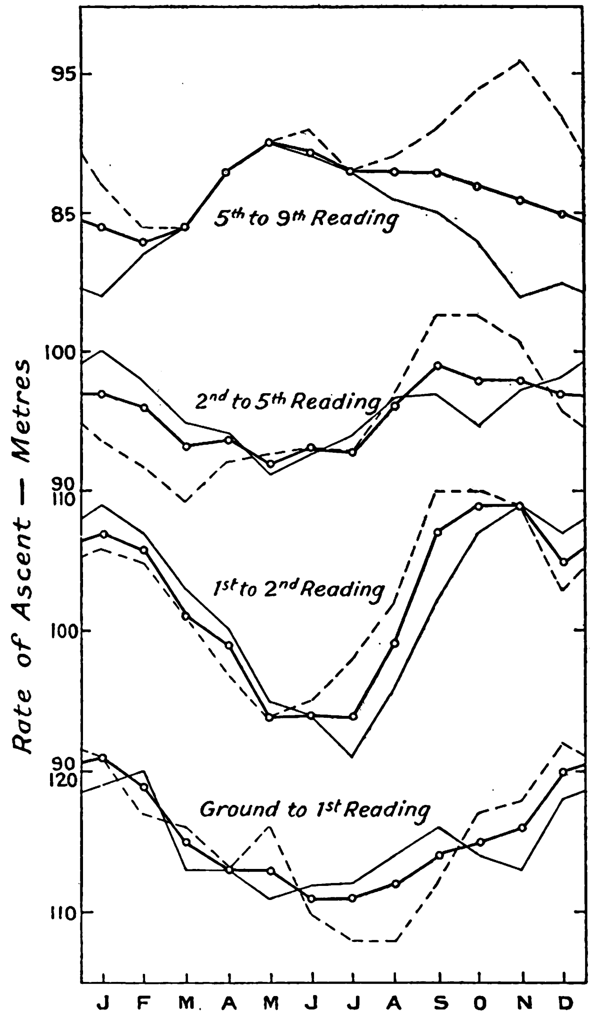

FIG. 3.—Annual Variation of Rate of Ascent at different heights.

It is not safe to generalise from the results at the 900-metre and the 1,100-metre levels, but the progressive changes in the curves as the height increases tend to confirm the reality of the effects shown. It is obvious that the diurnal variation is of great importance in determining the nature of the curves, and before the processes can be fully understood, observations at more frequent intervals during the day are needed. The true mean for the day may differ very considerably from the mean of the 09.30 and 15.30 hours ascents. One of the most prominent characteristics is the great height in the afternoon in the spring months and the low height in the morning. The explanation is not at first obvious, but it is suggested that in the morning the convection currents do not, as a rule, reach beyond 500 metres and that there is an inversion above them which checks the balloon's ascent. In the afternoon, on the other hand, the convection extends to beyond 1,100 metres. The reason for the low heights in the later summer and early autumn afternoons is not clear, but again the development of stable layers is probably involved. The sea breeze may be one of the important factors. In winter there is scarcely any difference between morning and afternoon ascents.

The results suggest very strongly that the rate of ascent varies with the turbulence. This does not necessarily mean that the whole effect is due to turbulence. The lapse rate is probably very important, but since turbulence and lapse rate are likely to vary together, it is difficult to disentangle the two effects. We are of opinion, also, that when there is a rapid change of velocity with height there is a pseudo-reflection of the balloon from the upper layers and a reduced rate of ascent.

It would have been interesting had time been available to have computed the rates of ascent at various levels as well as during various intervals after the release of the balloon. It is probable that more consistent results would have been so obtained.

5.—VARIABILITY OF HEIGHT.

Fig. 4 and 5 give the frequency per thousand with which various heights were reached by balloons at different readings for 09.30 and 15.30 and the mean for the two, and for the summer (December to February) and winter (June to August) quarters of the year. The number of observations and the standard deviation at each reading are given in Table II. The height scale for the second reading is

TABLE II.—NUMBER OF OBSERVATIONS AND STANDARD DEVIATION.

Reading.	1		2		5		9		11	
	No. of Obs.	Stand. Dev.	No. of Obs.	Stand. Dev.	No. of Obs.	Stand. Dev.	No. of Obs.	Stand. Dev.	No. of Obs.	Stand. Dev.
		m.		m.		m.		m.		m.
09.30	568	33	801	56	752	114	510	154	338	164
15.30	510	33	635	62	585	134	423	196	328	229
Mean	1078	33	1436	58	1339	123	933	175	666	200
Dec.-Feb.	352	39	425	72	432	156	295	198	210	234
Mar.-May	339	31	452	47	428	109	313	143	228	148
June-Aug.	249	25	380	40	350	82	238	125	162	120
Sept.-Nov.	294	34	377	63	357	139	245	197	162	209

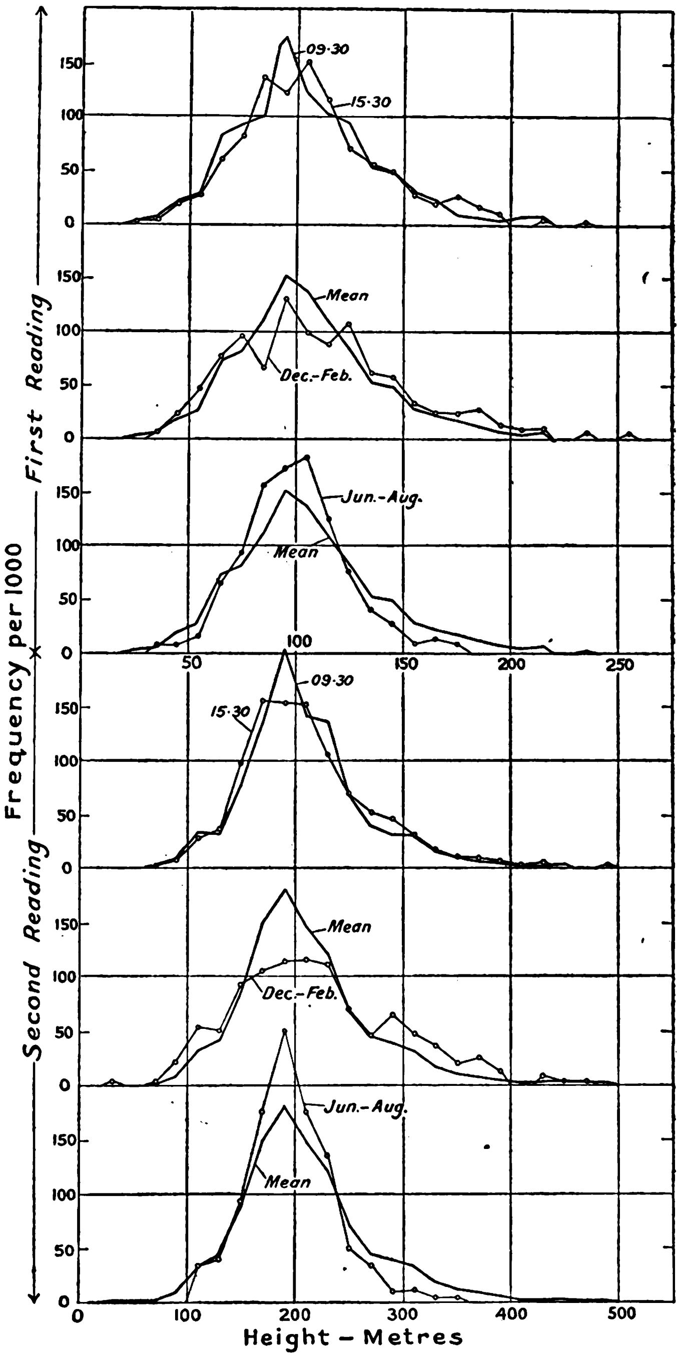

FIG. 4.—Height Frequencies at 1st and 2nd Readings.

double that at the fifth and ninth, and for the first reading it is again doubled. At each height the top curves show the frequencies at the 09.30 and 15.30 ascents respectively, the middle ones the mean of these two and the frequency in the summer quarter, and the lowest curves the mean once more and the winter quarter frequencies. Data for the eleventh reading are not plotted but are given in

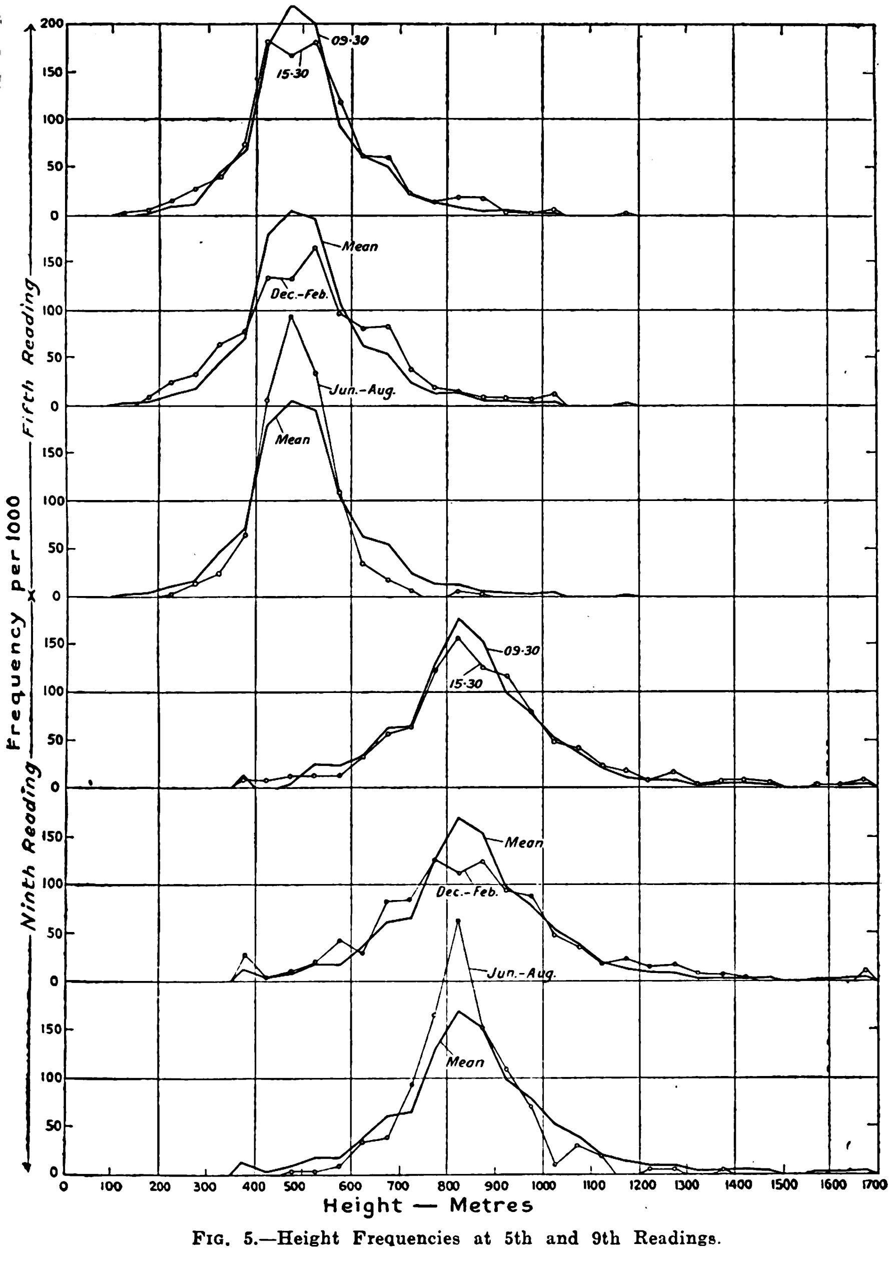

FIG. 5.—Height Frequencies at 5th and 9th Readings.

TABLE III.—HEIGHTS AT ELEVENTH

Height, Metres × 10 From	40	45	50	55	60	65	70	75	80	85	90	95	100
To	45	50	55	60	65	70	75	80	85	90	95	100	105
09.30 - -			15		9	6	34	26	54	75	87	131	189
15.30 - -	3	12	3	18	10	14	19	41	36	42	97	100	123
Mean - -	1	6	9	8	10	11	26	33	45	59	92	116	153
Dec -Feb. -	10	10	22	13	17	18	47	34	59	90	92	95	85
June-Aug. -				6	3	12	12	36	30	100	118	180	189

Table III. As was to be expected, the distribution is skew in every case, but the skewness decreases as the height increases. There is less variation possible on the down side of the mean height than on the up side owing to the nearness of the ground. The variability is in all cases greater in the afternoon than in the morning and in summer than in winter. The standard deviation is very high and increases with height. In winter it is little more than half what it is in summer. The overwhelming importance of turbulence is again shown by the features mentioned. It is indicated also by the fact that the height for different times of day and seasons of the year at any one reading varies in the same way as the standard deviation. The greater the variability in height the greater the mean height. The decrease in the mean rate of ascent with height is evidence in the same direction.

6.—RELATION TO VELOCITY.

In Table IV. the mean heights and rates of ascent are given for four separate velocity classes, the limits of which are indicated at the head of the table. The classification is according to the velocity at 500 metres. Mean heights and rates of ascent are given for all the morning and all the afternoon observations separately and for the two combined. Mean heights are given also for four different seasons. We will consider first the results which apply to the whole year. In the lowest layer the rate of ascent is greatest for light winds. This points to the turbulence due to surface heating in this layer being more effective in increasing the rate of ascent than wind turbulence. The heat turbulence would be greater in the lowest layer under conditions of calm or light winds than in stronger winds when larger masses of air are brought into contact with the surface and lapse rates near the surface would be reduced. The reason for the greater efficiency of the heat turbulence, we suggest, is the presence of more eddies or vertical currents of dimensions of the same order as that of the balloon and its wake. Probably, also, the proportion of vertical to horizontal movement is greater than in wind turbulence. When the balloon is at the boundary between ascending and descending currents it would tend

READING. FREQUENCIES PER THOUSAND.

105 110	110 115	115 120	120 125	125 130	130 135	135 140	140 145	145 150	150 155	155 160	160 180	180 200	200 220	
139	79	60	38	28	21	6	2	4	3		3			09.30
120	108	85	56	30	24	3	11	13	12	3	12	6	3	15.30
130	93	72	48	28	22	5	6	9	7	2	7	3	2	Mean
129	83	46	43	37	10	11	15	25	10		10		5	Dec.-Feb.
152	84	33	30		6	6		6						June-Aug.

to be deflected into the ascending one. For the light winds the heat effect is greatest in the morning when the solar radiation is increasing, whereas, in the afternoon, it is decreasing and conditions are more stable. In the stronger winds the reverse is the case, the amount of heating then probably depends more directly on the actual temperature of the ground. At the higher levels the rate of ascent is always greatest in the afternoon owing to the gradual upwards extension of the heat turbulence.

The rate of ascent is greater in strong than in light winds at the higher levels owing to the mechanical turbulence due to velocity. Even here, however, two effects are apparent. The greater efficiency of small-scale than large-scale turbulence is indicated by the distribution of the rates of ascent in the four velocity classes. Between the first and second readings these are 93, 106, 106 and 100 metres, and between the second and fifth 93, 97, 99 and 98 respectively. In each case there is a tendency for the rate to fall off at the highest velocity. The turbulence due to the very strong winds extends to greater heights and if observations above 500 metres were available at the highest velocities it is almost certain that they would give the highest rates of ascent. A large proportion of the eddies in strong winds reach dimensions which are very large compared with those of the wake of the balloon and it appears that they are, in consequence, not so effective in increasing the rate of ascent as those of smaller dimensions.

For the different seasons, the number of observations is not sufficient to give very reliable means. The results are in general agreement with previous conclusions. The low rates of ascent in winter, particularly in light winds, show the importance of heat turbulence.

7.—RELATION TO WEATHER.

The relation of the balloon heights to weather conditions is very difficult to elucidate without simultaneous observations of temperature and pressure at the various levels above the surface. There seems to be little doubt that the most important factors controlling the rate of ascent of the balloon are turbulence and lapse rate. The

TABLE IV.—RELATION OF HEIGHT AND RATE OF ASCENT TO THE VELOCITY OF THE WIND AT 500 METRES.

Velocity.	0 to 4.9 m/s.					5.0 to 9.9 m/s.					10.0 to 15.0 m/s.					> 15 m/s.		
Reading.	1	2	5	9	11	1	2	5	9	11	1	2	5	9	11	1	2	5
09.30 Height (m.)	126	220	495	831	995	114	219	514	844	1011	116	217	507	855	1012	108	207	501
Rate (m/s.)	126	94	92	84	82	114	105	98	82	84	116	101	97	87	78	108	99	98
15.30 Height (m.)	118	206	490	828	1014	119	228	515	870	1042	113	225	530	897	1142	111	214	509
Rate (m/s.)	118	88	95	84	93	119	109	96	89	86	113	112	102	92	122	111	103	98
Mean - Height (m.)	121	214	492	829	1000	117	223	515	858	1027	115	221	517	873	1050	110	210	503
Rate (m/s.)	121	93	93	84	86	117	106	97	86	84	115	106	99	89	88	110	100	98
Summer (Dec.-Feb.)																		
09.30	133	239	528	861	998	119	227	524	847	1020	125	233	530	804	915	98	204	525
15.30	120	201	465	763	957	132	248	539	904	1075	118	235	517	875	907	125	205	582
Autumn (Mar.-May)																		
09.30	122	211	486	825	1001	111	219	507	852	1014	112	215	520	875	1085	106	204	516
15.30	109	205	494	853	1040	111	209	487	833	987	119	234	538	942	1102	130	221	520
Winter (June-Aug.)																		
09.30	110	198	466	816	989	112	204	482	835	1006	112	215	501	883	1207	112	209	502
15.30	112	198	473	820	987	106	209	486	840	990	106	222	507	903	1178	107	205	487
Spring (Sept.-Oct.)																		
09.30	122	233	489	806	975	113	225	528	844	1014	120	213	492	842	1330	107	202	476
15.30	122	222	531	864	1035	123	245	544	911	1130	110	215	533	918	971	110	228	518

TABLE V.—RELATION OF HEIGHT TO TYPE OF WEATHER.

Velocity.	0 to 4.9 m/s.					5.0 to 9.9 m/s.					10.0 to 15.0 m/s.					> 15 m/s.		
Reading.	1	2	5	9	11	1	2	5	9	11	1	2	5	9	11	1	2	5
Type.	Deviations in Metres of Heights from Mean.																	
C3e	− 6	− 6	+20	+39	+44	+ 6	−11	− 2	+ 39	−45	−12	−16	− 9	+24	+75	−13	−16	−22
C2e	+21	−11	−21	+33	+40	− 9	−12	+ 3	− 3	0	− 7	+ 3	+ 3	+ 9	−30	+ 5	+ 4	+14
C2p	+ 9	+ 6	+20	+17	+21	− 7	−11	− 1	+ 22	− 1	+ 3	+ 8	+ 4	+23	+ 1	+14	+16	+57
C1p	− 4	− 5	−29	−71	−50	+ 4	+ 8	−18	− 31	−29	+ 2	+ 4	−27	−53	−80	+19	+30	+13
Ce	0	− 5	+10	+44	+43	− 7	−14	− 2	+ 24	+25	−10	−10	− 7	+17	+17	−10	−12	−15
Cp	− 2	0	−10	−19	−25	0	+ 2	−12	− 12	−17	+ 2	+ 5	−14	− 7	−48	+18	+25	+37
S	+ 2	+ 2	−13	−24	−47	+ 4	+11	+ 2	− 25	−24	+ 6	+ 4	+47	−23				
A	− 1	− 1	− 2	− 8	− 2	− 2	− 4	−23	−118	−32	+19	+15	+26	+53	+ 2	+26	+13	+23
	Number of Observations.																	
C3e	7	18	21	17	15	56	71	72	69	61	86	100	102	64	9	88	91	88
C2e	3	8	7	7	7	26	37	34	28	23	43	44	41	29	8	21	22	21
C2p	8	18	17	16	14	56	65	63	59	44	61	62	58	40	7	27	26	19
C1p	26	37	34	28	23	118	139	128	108	84	83	87	81	51	15	24	23	15
Ce	13	32	34	29	27	91	118	115	105	92	131	147	146	94	18	109	113	109
Cp	37	58	55	46	39	184	214	201	177	137	150	156	145	96	23	53	52	37
S	46	87	91	79	61	114	134	135	100	80	22	23	18	11				
A	103	269	266	220	195	82	104	95	81	64	17	18	18	10	3	2	2	2

C=cyclonic,
S=anticyclonic wedge or shoulder,
A=anticyclonic,

e=equatorial,
p=polar,

1=direction of wind from 180-259°
2= ,, ,, ,, 260-339°
3= ,, ,, ,, 339- 22°

two are not, however, independent and each is to some extent a function of wind velocity. It is probable that the moisture content of the air is important also, but we have not attempted to investigate its effects in this paper. Other factors are temperature, pressure and the variation of wind velocity and direction with height. It would take a very large number of observations to enable the effect of these elements to be isolated. Again, although certain conditions may be, in general, characteristic of particular types of weather, these conditions may be very seriously modified at any station by the effects of local topography, especially in the lowest kilometre. A stable air mass, for instance, may be converted into an unstable and turbulent one through passage over ranges of hills. There are certain types of weather in which we would expect to find a predominance of ascending or descending air currents, but it is fairly obvious that in any particular type of air the mean rate of ascent or descent must be very small. Our results are certainly in accord with this. It must be emphasised, too, that departures from normal rates of ascent are very seldom measures of true vertical currents in the atmosphere. They are due chiefly to eddy motion. This is obvious for many reasons, amongst which may be mentioned (*a*) the known existence of eddy currents; (*b*) the fact that eddy conductivity is sufficient to account for the greater part of vertical heat transference; (*c*) it would be impossible to account for a large portion of the negative departures as being due to the descent of cold air; (*d*) this becomes especially clear when individual ascents are considered; (*e*) when low cloud or smoke is present, there is seldom evidence of such vertical currents although the rate of ascent of the balloon is still variable; (*f*) there are occasions when the balloons do get into ascending currents, and their behaviour is then quite different from their behaviour when the rate of ascent is undergoing positive variations of the more usual kind; (*g*) more rarely there are indications of similar effects in true descending currents; and (*h*) it is impossible to account for mean results as being due to true vertical currents. In fact, it does not seem to be possible to determine true vertical currents by means of pilot balloons.

In Table V. the deviations from the mean heights are given for the four velocity classes in a number of different types of weather. The second half of the table gives the number of observations on which each height depends. Values depending on less than 20 observations are certainly not reliable.

The South-Westerly direction, 1, faces towards the sea, and there is comparatively little obstruction. Coming from direction 2, air would have to travel over ranges of hills. From direction 3, there is, again, little obstruction by hills. Winds from the remaining directions are infrequent, mainly light, and occur most often in anticyclonic weather. They have not been treated separately here, but are included in the four main types of Table IV.

The first row of the table, type C3e, refers to equatorial air from a northerly direction in a cyclonic pressure distribution. This air will usually be warmer than the ground surface and tends, therefore, to be stable in the lower layers. The heights are correspondingly low. Since the heaviest and most general rains in

Australia, though not the most frequent, are experienced in air of this type, some process must be at work which tends to produce instability in it. One would, therefore, expect it to be unstable in the upper levels and the balloon heights to be above normal in consequence. This is seen to be generally the case at the ninth and eleventh readings. For velocities greater than 15 m/s. these winds give the lowest mean heights. They receive the least assistance from heat turbulence owing to their high temperatures. An important fact is that they form more than half of the winds of velocities greater than 15 m/s. A large proportion of those with velocities between 10 m/s. and 15 m/s. also are of this type. These winds are frequently in excess of the gradient wind and appear to be reinforced owing to gradients in the upper air. In fact, a gradient in the upper air for North-Westerly winds seems to be constantly superimposed on the surface pressure distribution, and its effects to be transmitted downwards to the winds near the surface. The Northerlies frequently set in strongly in the upper air very soon after the passage of the centre of an anticyclone.

The C2e winds have come over broken country and should be less stratified than the C3e class. They give heights which are generally above the mean at the higher velocities. Otherwise, no prominent characteristics are indicated.

The polar winds (C2p) from the same direction quite definitely show heights above the mean for the strong winds. In this case the air is usually colder that the ground surface and there is considerable heat turbulence.

Most of the winds from direction 2 are from N. of W. and the table shows the overwhelming predominance of winds from the north-west quadrant.

Polar winds from the south-west (C1p) give low heights for the low velocities. They are influenced largely by the sea breeze effect and would frequently have a temperature inversion at a moderate height. When above 15 m/s. these winds are usually very cold Southerly winds which have had a far southern origin and are most characteristically polar. The rate of ascent is higher in them, at least in the low levels, than in the other strong winds.

The equatorial and polar winds respectively are grouped together in the fifth and sixth rows of Table V. The Ce winds have the characteristics of the C3e winds which predominate in them. The polar cyclonic winds give heights below the mean for winds up to 15 m/s. except at the first two readings. At greater velocities the heights are considerably above the mean. This seems to indicate that polar air is normally stable, but is frequently rendered unstable in its lowest levels owing to its low temperature. When very strong polar winds have doubtless been rendered unstable by the turbulence due to their velocity and at the same time to their being heated rapidly from the ground surface.

This contrast as regards average conditions as to stability in the upper levels between equatorial and polar winds is very important. As has been mentioned, the heaviest and most general rains in Australia fall from warm air coming from the north and north-west, frequently extending in a band right across the Continent. A good rain year is characterised by an unusual amount of rain with such an origin. The processes by which this rain is produced have never been elucidated. The most important probably are a general cooling by radiation and a dynamical uplift. The reverse processes are, we consider, the causes of the stability of polar air. The equatorial winds have, of course, a much higher moisture content than the polar. The most typically unstable air is young polar air and ascending currents are most conspicuous in this type. Nevertheless, the older polar air which constitutes the greater part of the mass is stable.

The air in the anticyclonic shoulder will generally be polar air, and, according to the table, it has the same characteristics.

In the anticyclone proper, the winds are nearly always light. One would in general expect stable air, though frequently the lower kilometre or so will be rendered unstable by surface heating. For the light winds the heights are all very slightly below the mean and for those between 5.0 m/s. and 9.9 m/s. distinctly so, especially at the later readings. For the very few stronger winds, the heights are above the mean, but it is very doubtful whether these winds have been correctly classified. They were probably in most cases cyclonic.

SUMMARY.

1. The wind régime at Melbourne is described, the prevalence of North-westerly winds at all levels being emphasised.
2. The mean rate of ascent is shown to be above that given by J. S. Dines's formula near the surface but below it above 200 metres.
3. There is an annual variation in the mean rate of ascent, which is highest in summer and lowest in winter.
4. The rate of ascent, as has been found at other places, is very variable, the departures from normal being sufficiently serious to render the single theodolite method insufficiently accurate for at least some practical purposes. The standard deviation of the height after various intervals from the commencement is given and the distribution of the departures shown.
5. There is evidence that heat turbulence is more effective in increasing the rate of ascent near the surface than the turbulence produced by high winds. This the authors believe to be due to its being on a smaller scale.
6. By far the most important factor causing variations in the rate of ascent is turbulence. The greater the turbulence, the greater the mean rate of ascent. It is believed, however, that with the same amount of turbulence the rate of ascent would be appreciably less in stable than in unstable air.
7. The diurnal variation in the rate of ascent and the variation with diffierent types of weather are complicated and depend chiefly on the development of stable or unstable conditions in the different air layers.
8. There is considered to be evidence of definite ascending currents in the spring months. Except in the case of upward currents of considerable vertical extent, pilot balloon observations are not calculated to give a measure of true vertical currents as distinct from those due to turbulence.

THE IONISATION OF THE LOWER ATMOSPHERE.

By Professor J. J. NOLAN (University College, Dublin).

The electrical conductivity of the atmosphere depends upon the number of electrical carriers or ions that it contains, on the charges carried by them, and on their mobility, that is, the velocity with which they move in an electric field. In the lower layers of the atmosphere the conductivity is normally due almost entirely to the ordinary "small ions"; the charge on each ion is therefore the electronic charge and the mobilities are of the order 1 to 2 cm. per second in a field of 1 volt per cm. The number of the ions present in unit volume of any part of the atmosphere at any time depends on the rate at which they are being produced or introduced into that volume and on the rate at which they are being destroyed or removed.

The chief agencies which produce ions in the lower atmosphere are the α, β and γ rays from radio-elements of the radium and thorium families present in the air, the γ rays from radio-elements present in the soil and the penetrating rays discovered by Hess and Kohlhörster. Processes such as combustion, the breaking of waves and the splashing of raindrops also contribute to the ionisation of the atmosphere to an extent which it is difficult to estimate. It is probable, however, that the total effects of such actions, which are necessarily local and fugitive in character, are small in comparison with the wide-spread and steady effects of the ionising radiations. While considerable local variation must be allowed for owing to differing characters of soil and differing meteorological conditions, it is agreed that the average rate of production of ions by the ionising radiations over the land is about 10 of each sign per c.c. per second. Over the sea, however, when sufficiently remote from land influences, the radio-active content of the atmosphere is so small that the greater part of the ionisation must be due to the penetrating radiation alone. Since this radiation produces everywhere about 1.5 pairs of ions per c.c. per second at sea level, the rate of production of ions over the oceans can be little higher than this value.

Laboratory experiments with ions in purified air have shown that, when the containing vessel is so large that losses to the sides can be neglected, the ions are destroyed only by combination among themselves, positives with negatives. The number of collisions which are effective in destroying ions will be proportional to the product of the concentrations of the two kinds, and since both signs are usually present in equal numbers, the rate of loss will therefore be proportional to n^2, n being the number of either positive or negative ions present per c.c. A balance is set up when the rate of loss is equal to the rate of production: then $q=\alpha n^2$, where q is the rate of production per c.c. and α is a constant. The value of α in air under normal conditions is about 1.6×10^{-6}. If the relation $q=\alpha n^2$ could be applied to atmospheric air, we should expect to find over land areas where $q=10$, that positive and negative small ions were present in concentrations of about 2,500 per c.c. But the average values are certainly less than one third of this, and in the neighbourhood of cities, observers who are careful to distinguish the small ions from other charged particles find that the number sinks frequently below 100 per c.c. It is natural to attribute the discrepancy to the presence of dust in the atmosphere and to assert that the number of small ions is reduced owing to their capture by dust particles. But the question of dust in the atmosphere demands very careful examination.

In 1879 John Aitken, of Falkirk, began a series of researches on the mechanism of cloud formation, which he pursued almost without interruption till his death in 1919. He showed that when moist air is cooled, condensation occurs around certain centres which are always present in ordinary air. The number of these centres varies very much, attaining values of hundreds of thousands per c.c. when the air is much contaminated, but sinking to some hundreds per c.c. in the pure air of the Alps and of the Scottish Highlands. Aitken called these centres or nuclei " dust particles " and called the various types of apparatus which he devised to study them " dust counters." It would be better, however, to call these particles simply " condensation nuclei," for later work has shown that they are quite different from, and have practically no connection with, true dust. The true dust, that is the minute particles of solid matter suspended in the atmosphere, is best studied by means of the " jet dust counter " devised by Dr. J. S. Owens. In this instrument a certain volume of moist air is forced through a narrow slit and the dust it contains is driven on to a sheet of glass where it can be examined microscopically. Experiment has shown that the true dust is generally present in much smaller quantities than the condensation nuclei. Observations for nine months in Dublin gave for the dust particles an average figure of 1,600 per c.c., while the number of condensation nuclei was about 30,000 per c.c. Experiments tend to show that the true dust particles do not act as centres of condensation; that, in fact, there is no connection between the two classes of bodies except that to a certain extent they have a common source in such processes, for example, as combustion.

In a contaminated atmosphere such as that of a city, both the condensation nuclei and the true dust are present. In country districts the amount of true dust is very small, but there are always present a considerable number of condensation nuclei. For example, measurements made during two summer months in the mountainous districts of West Cork gave values for the concentration of nuclei which on only one occasion fell below 400 per c.c. Observations made recently during four winter months in an even more sparsely populated district in the Wicklow mountains gave values which lay, for the most part, between 500 and 2,000 per c.c. While no doubt the true dust particles pick up some of the small ions, yet, on account of their relatively small numbers in most places, the effect they exercise may be disregarded in comparison with that of the condensation nuclei. Even in city air, where the dust particles are present in concentrations of some thousands, their direct effect on the ionisation seems to be relatively negligible. The condensation nuclei, picking up small ions, acquire charges, some positive, some negative, and, in fact, become ions of a new kind. There is no doubt, in fact, that the charged nuclei are identical with the "large ions" discovered by Langevin in Paris in 1905. In regions where the nuclei of condensation are plentiful, the large ions will far exceed the ordinary or small ions. Thus the number of large ions per c.c. of the air of Dublin is about 10,000, while the number of small ions is about 120.

It is clear that the original theory of the relation between the rate of production of ions and the number present must be modified. It is easier to begin by considering the process of formation of large ions. Positive large ions are formed by the union of positive small ions with uncharged nuclei, and they are destroyed in two ways, first, by combining with negative small ions, and second, by combining with negative ions of their own size. The rate of the second process is known and is so small as to be negligible from our present point of view. The rate of formation of the positive large ions might be supposed to be proportional to the concentration of uncharged nuclei and to the concentration of positive small ions, while the rate of their destruction might be supposed to be proportional to their own concentration and to that of the negative small ions. The number of the positive large ions will become steady when the processes of formation and destruction balance, and it is easily seen that this equilibrium will involve that a constant fraction of the total nuclei will be positively charged. Similarly a constant fraction will be negatively charged. Experimentally it is found that the positive and negative large ions are usually present in equal numbers, and that together they constitute from 50 to 60 per cent. of the total nuclei.

Considering the matter from the point of view of the small ions, our original equation for equilibrium in pure air was $q=\alpha n^2$. We now recognise that, in addition to combining among themselves, the small ions can combine with two classes of bodies which are present in certain definite relative concentrations, the uncharged nuclei and the large ions of opposite sign. Assuming as before that the rate of destruction is proportional to the concentrations of the combining particles, we might write our equation $q=\alpha n^2+\alpha' nN_\pm$ where $N_\pm$ is the concentration of positive or negative large ions, or as $q=\alpha n^2+\alpha'' nN$ where N is the concentration of nuclei of all kinds, α' and α'' being constants. Where nuclei are plentiful, the first term is negligible, and we have $q=\alpha' nN_\pm$ or $q=\alpha'' nN$. The first form of the relation is convenient if we are dealing with measurements of large ions, the second if we are concerned with the total amount of nuclei.

This relation between q, the rate of production of ions and n, the number of small ions present in atmospheric air was arrived at independently and verified experimentally by Schweidler in Innsbruck, by A. D. Power in America and in my laboratory in Dublin. As far as concerns the term $N_\pm$ (or N) which occurs in the equation, it was considered to have been verified by further experiments in Innsbruck and Dublin. Recent work, however, appears to show that the range of these experiments was too limited, and that, in fact, the relation as stated above must be modified considerably in order to fit the experimental facts.

Before discussing the various kinds of evidence that are available from laboratory and field experiments, it is convenient to consider briefly the experimental methods adopted for determining the quantities of small and large ions in the atmosphere. In each case the method is to draw the atmospheric air through a condenser system in which is maintained an electric field of sufficient strength to extract all the ions sought. The ions are collected on the insulated part of the condenser and the total charge recorded by an electrometer. In an apparatus designed for the measurement of small ions it is usual to provide for a rapid air current, so that in a given time the greatest possible electric charge may be collected. Care should be taken that ions are not prevented from entering the apparatus by any electric field, whether one associated with the apparatus itself or with the surroundings. Care should also be taken that the field in the condenser is not more than that requisite to extract the small ions. Many observations of atmospheric ionisation are practically valueless, as the field in the apparatus is so great that, in addition to the small ions, a considerable fraction of an unknown content of large ions is captured.

The principal difficulty in connection with the measurement of the large ions arises from their very low mobility, the velocity of these ions in a field of 1 volt per cm. being only about .00033 cm. per second. In most places where they have been observed, they are present in greater concentrations than the small ions; so that, in order to obtain a measurement, less air has to be dealt with. In fact, on account of their sluggishness, a combination of slow air stream, long path and strong electric field must be arranged. The number of the ions is usually calculated by assuming that each of them carries the electronic charge, 4.77×10^{-10} electrostatic units. In the case of large ions in general this procedure is not without risk, as it has been shown that in some cases they can carry three or more electronic charges. It is therefore of some interest to show how the charge on the atmospheric large ion has been determined.

The total number of nuclei in a sample of air was determined by means of Aitken's apparatus, and again, the number remaining when all the charged nuclei had been extracted by an electric field. The difference was the number of charged nuclei or large ions, of which half were positively and half negatively charged. The charge on the ions extracted was determined from an electrometer reading. Then, knowing the number of ions and the charge they carried, the average charge per ion could be calculated. A set of 15 observations gave for the charge per large ion a mean value agreeing within 5 per cent. with Millikan's value of the electronic charge. We can therefore with some confidence assume that the atmospheric large ions normally carry single charges. The experiment is interesting from another point of view, as it confirms our identification of the Langevin large ion with the charged Aitken nucleus.

What is the constitution of the small and large ions? This must remain to some extent a matter for speculation. There is some reason for believing that the nucleus, which when charged becomes a large ion, is an aggregate composed of water, formed around some primary kernel of a hygroscopic character. I have calculated that the radius of the ordinary large ion is about 4.1×10^{-6} cm.; other calculations give a slightly larger value. This is about one tenth of the average radius of the particles collected by the Owens dust counter. Some years ago I suggested that the small ions were aggregates of a much smaller size—groups of about 20 water molecules. Evidence is gradually accumulating in favour of this theory of the constitution of the small ion.

Returning to the equilibrium equation $q = \alpha' n N_{\pm} = \alpha'' n N$ proposed for atmospheric air containing nuclei, we may consider the attempts that have been made to verify it experimentally. These have differed in form, but fundamentally they all involve making determinations, for different samples of air, of the rate at which ions are being produced in each case, of the number of small ions and of the number of nuclei or of large ions present. From these observations the value of the appropriate coefficient, which has taken various forms with different workers and which appears in this paper as α' or α'' can be determined. It is found that the value of α' is by no means constant. It undergoes fluctuations of a 2:1 order, which are well outside the range of uncertainty in the quantities measured. Such variations are to be found in air for which q is the same and the concentration of nuclei approximately the same. The cause of this unsteadiness has not yet been properly explored, but it is possible that it is due to the fact that neither the small ions nor the large ions are a strictly homogeneous and unvarying class. Evidence of the existence of ions of intermediate sizes has been brought forward from time to time by different observers, but there has been no systematic investigation. The difficulties of such an investigation for atmospheric ions are very great on account of the large and rapid changes of ionic content which occur in the free air. A variation in the character of the constituents which make up the two groups of bodies which we measure as small ions and nuclei could without much difficulty be made to account for the fluctuations observed. Whatever may be found to be the explanation, these fluctuations served for a time to mask a real variation in the calculated value of α'. They also had the effect of lessening any stress that might be laid on the fact that the values deduced for α' from the results of different observers showed considerable disagreement. It was only when observations were made on air in which the normal nucleus content of a city atmosphere had been artificially altered, so as to get a range of very high and very low values, that the real variation became apparent. It was found that, allowing for all uncontrollable fluctuations, the value of the coefficient α' decreased for air of high nucleus content and increased for air of low nucleus content, the direct proportionality between q and n meanwhile holding good. The variation occurs in such a way that $\alpha' \sqrt{N}$ is approximately constant. It is further found that by taking account of this variation we can harmonise the results of different observers, since the product $\alpha'\sqrt{N}$ has about the same value for all available sets of reliable data.

The variation in α' might be explained by assuming that the size or character of the nuclei varied according to their degree of concentration in the air. While this possibility must not be excluded, it is difficult to find a satisfactory explanation on such lines. It is more logical to introduce a new coefficient which will have more of the character of constancy and to re-write the equilibrium equation as $q = \zeta n \sqrt{N}$. This is at least empirically true over a considerable range, ζ having the value 55×10^{-5}. In conditions where the nuclei are few, the equation becomes $q = \alpha n^2 + \zeta n \sqrt{N}$. This equation implies that the law of mass action, according to which the collision frequency between two sets of bodies should be proportional to the product of their concentrations, does not apply to the collisions between small ions and nuclei which result in combination. It is difficult to see any theoretical justification for the occurrence of the square root of the nucleus concentration, but it is found that a law of this form is necessary not only to fit the results of laboratory experiments but to render coherent the observations of ions and nuclei made in the free atmosphere.

It has not hitherto been found possible to make direct determinations of q, the number of pairs of small ions produced per c.c. per second in the free atmosphere. But if such a relation as $q = \alpha n^2 + \alpha' n N_{\pm}$ or $q = \alpha n^2 + \alpha'' n N$ could be firmly established and if the value of α' or α'' were accurately known, then it would be only necessary to make observations of small ions and large ions or nuclei under conditions of equilibrium and the value of q would be found. Calculations of q made in this manner on the basis of observations in city air appear fairly satisfactory, but again, difficulties arise when calculations are made from observations in purer air. The value of q calculated for any place appears to vary with the number of nuclei, decreasing as the concentration of nuclei decreases. The difficulty is accentuated when observations are made in very sparsely populated districts where the concentration of nuclei sometimes sinks to very low values. The values of q calculated for such occasions on the basis of the formula $q = \alpha n^2 + \alpha'' n N$ are far too small to be possible, in many cases well below the 1.5 pairs of ions per second, which is the contribution of the penetrating radiation alone. The application of the formula $q = \alpha n^2 + \zeta n \sqrt{N}$, however, provides a solution which, as far as observation has gone, is fairly satisfactory. For any given place the calculated value of q, while still showing day-to-day variations, lies within the limits to be expected. Comparing the results for different places, the tendency shown in earlier calculations for the mean values of q to be rather widely separated has disappeared.

As an example of the application of the two formulæ, some simultaneous observations of small ions and nuclei made recently in County Wicklow are tabulated. The observations are set out in decreasing order of concentration of nuclei. They are selected from a much larger number and are thought to be fairly representative of the associated variation of the ions and nuclei. Observations believed to be disturbed by rain or by the presence of fresh combustion products have not been included.

OBSERVATIONS OF SMALL IONS AND NUCLEI, GLENCREE, CO. WICKLOW (NOVEMBER, 1928—FEBRUARY, 1929).

Nuclei per c.c. N	Small ions per c.c. (Means of + and —). n	Pairs of ions produced per c.c. per sec. q	
		Old Formula.	New Formula.
12,000	205	9.0	12.4
7,900	140	4.1	6.9
5,600	195	4.1	8.0
2,200	420	3.6	11.1
2,130	160	1.3	4.1
1,050	635	3.1	11.8
770	555	2.1	9.7
600	345	1.0	4.9
465	425	1.0	5.3
300	790	1.9	8.4

In calculating q from the older formula, the value of α'' employed was a weighted mean of the best available results of laboratory experiments made on air in which the concentration of nuclei was about 25,000 per c.c. The choice of a value for α'', however, is not of much importance, as no value which is within the limits of probability will, on the basis of the old formula, give values of q which are possible and at the same time show any approach to constancy.

It is not pretended that the new square-root formula gives a complete or final solution of the problem. It is to be expected that when more complete information is available, further modifications may be necessary. But at least a first approximation has been found. The rate of production of ions in the atmosphere is perhaps the most important element in the domain of atmospheric electricity. With further knowledge it may be possible, on the basis of observations of ions and nuclei, to calculate its value with confidence and to separate out and distinguish the contribution of the different ionising radiations and other sources of production of ions.

NOTE.—The original papers on which this article is largely based will be found in the *Proceedings of the Royal Irish Academy*, Sec. A, Vol. **37**, pp. 1, 58 and 71 ; Vol. **38**, pp. 1, 40 and 49, 1925-28.

Heavy Rainfall in Brazil

January, 1929, was a month of unusually abundant rainfall in parts of Brazil. Mr. Walter Blaber, of 34, Bedford Street, W.C.2, informs us that at Cambara in northern Parana 501 mm. (19.7in.) fell during the month, 92 mm. (3.6in.) falling on the 19th. Numerous depressions passed across the country, and not only were there heavy falls, but rainy weather persisted during most of the month. Jaguariahyva, in northern Parana, one of the stations of the Brazilian Meteorological Service, recorded 562 mm. (22.1in.) of rain, which is 2½ per cent of the 10-year average, and 26 rain-days.

REPORT OF THE COUNCIL

FOR THE YEAR 1928

[Submitted to the Annual General Meeting, January 16th, 1929.]

Although the year has not been marked by any outstanding events the Society continues to make progress, and the Council have been engaged in several undertakings which are not without importance to meteorology. Among these may be mentioned the endeavours to stimulate interest in the science by the Lecture Scheme, and to encourage the teaching of meteorology by the Prize Essay Competition for teachers. The debt on the premises of the Society has been further reduced during the year, but still amounts to £1,800. Many new Fellows have joined the Society, but these accessions have unfortunately been counterbalanced by the exceptionally large number of deaths, which has seldom been exceeded in our history. A serious loss to the Society and to the whole of meteorology was sustained by the death of Dr. Charles Chree, F.R.S., who filled the office of President during 1922 and 1923, and served for many years on the Council. Reference should be made to the successful flight across the Arctic Ocean carried out by one of our Fellows, Captain Sir Hubert Wilkins, in April. The Council had the pleasure of despatching, in the name of the Society, a telegram of congratulation to Sir Hubert on his achievement.

QUARTERLY JOURNAL AND MEMOIRS.—The standard of attractiveness in the *Journal* has been maintained, and has borne fruit in a steady increase of the number of copies ordered, in addition to those issued to Fellows. The Council are again indebted to two Fellows who have generously placed at their disposal the sum of £125 in aid of this publication.

Application was made again to the Royal Society for a contribution from the Government Publication Grant to assist the publication of the *Memoirs*. The Council gratefully acknowledge the receipt of a grant of £100, while regretting a reduction of £50, due, they understand, to the many calls on the Royal Society for similar purposes. It may be pointed out that the publication of these *Memoirs* was originally made possible by a grant from the Royal Society, and that no less than twelve *Memoirs* were issued during the year, of which the printing alone has cost more than £250.

The *Index* to the *Quarterly Journal*, 1901-1925, referred to in the last report, was published early in the year at a price of 2/6.

As its preparation has involved considerable outlay, the Council are unable to issue it free of charge, but the price has been fixed as low as possible in the hope that the majority of Fellows will avail themselves of this valuable work of reference.

MEETINGS.—Eight ordinary meetings have been held in the Society's rooms, and by permission of the Air Ministry, a special summer meeting took place at Croydon Aerodrome on May 31st. At this meeting a large number of Fellows and their friends were present, and special invitations were issued to members of the International Commission for Synoptic Weather Information. In addition, an informal meeting was held in the Fellows' room on October 17th for the discussion of certain *Memoirs*. This new departure proved very successful and the Council hope to repeat it.

PHENOLOGICAL REPORT.—The Report for 1927 was presented at the June meeting. Owing to the recent publicity given to this subject and the appeals sent out by the Phenological Committee for fresh observers in sparsely represented districts, the Report contains a larger number of observations than any previously published. This has entailed much more work on the Committee, and they were glad to avail themselves of the help of Mr. C. J. P. Cave in the preparation of the Report. The Council desire to place on record their appreciation of the work of the Committee.

FINANCE.—The accounts for the year will be found at the end of this Report. The balance to the credit of the Society is shown to be £752 7s. 9d., as compared with £666 18s. 0d. in 1927. This makes it clear that even with the generous donations in aid of the *Journal* and the grant from the Royal Society, the margin between current receipts and expenditure (including in the latter some repayment of debt) is small. This is largely due to the marked increase in the cost of publications. The Council do not wish to have to curtail these, but such a course may be necessary if the assistance referred to above is not forthcoming. They feel that for the publications they cannot have recourse to the balance which must be available for the redemption of the Society's debt. Six of the debentures were redeemed during 1928, reducing the amount under this heading to £1,800 on December 31st. It will be a considerable relief to the Society when the debt on the debentures is extinguished.

DINES MEMORIAL FUND.—As a memorial to its distinguished Past President, Mr. W. H. Dines, F.R.S., who contributed so greatly to our knowledge of the upper air, the Council decided to establish a fund which should bear his name, and invited contributions from the Fellows. The Society's own contribution is the handing over of its existing Research Fund, and the response to the appeal will be found in the printed accounts. The Council consider that the most suitable memorial to Mr. Dines would be a collected edition of his scientific writings. The material for such a volume is being compiled, and negotiations have been opened with a firm of publishers with a view to its production.

FELLOWS.—Particulars as to the number of Fellows are given in the following table:—

	FELLOWS.			HONORARY MEMBERS.
	ANNUAL.	LIFE.	TOTAL.	
December 31, 1927	**603**	**165**	**768**	**17**
Since elected	+46	+ 1	+47	—
Reinstated	+ 3	—	+ 3	—
Deceased	−16	− 5	−21	−1
Resigned, etc.	−33	—	−33	—
December 31, 1928	**603**	**161**	**764**	**16**

There is thus a slight decrease in the total Fellowship as compared with last year.

The Council record with much regret the deaths of the following Fellows, the dates in parenthesis representing the years of election:—

Dr. W. B. Blaikie (1887).
Flt. Lieut. L. H. Browning (1925).
Mrs. Lucy Cave (1913).
Dr. C. Chree (1910).
W. Haynes (1926).
Lt. E. L. D. Moore, R.N. (1928).
Dr. W. L. Moore, Hon. Member (1902).
J. J. Moubray (1909).
T. S. Muir (1901).
G. Muirhead (1878).
Dr. D. Murray (1887).
Hon. Anna J. Peckover (1927).
Dr. C. M. Powell (1883).
Duke of Richmond and Gordon (1909).
Rev. D. Holland Stubbs (1917).
J. Turner (1871).
J. R. Twentyman (1901).
W. F. Vint (1926).
P. D. Warren (1907).
Rev. R. W. Whiston (1927).
W. B. Wilson (1895).
J. G. Wood (1893).

Mr. Mellish's Meteorological Library.—As referred to in last year's Report, the Council arranged that Mr. Mellish's meteorological library, which was entrusted to their disposal, should be presented to the University of Nottingham. The transfer of these books to the new University buildings was effected in the summer months, and the library is now available for use of students.

Donations.—During the year the following donations have been received:—

A copy of Luke Howard's "Barometrographia," bound in one volume, presented by Miss A. M. Hodgkin, grand-daughter of Luke Howard.

Photograph of a tornado cloud taken in Minnesota, presented by the proprietors of the *Illustrated London News*.

Symons's historic Brontometer or thunderstorm recorder, presented by Mr. Spencer C. Russell.

A list of the donors to the Library will be found in Appendix II.

COMMITTEE ON ATMOSPHERICS.—The investigation on the connection between atmospherics and the weather is continuing and much information relating to thunderstorm data all over the world is being collected. The Committee hope to publish a further Report when the material has been fully discussed.

AWARDS.—*The Buchan Prize*.—The third award of this prize has been made to Dr. Harold Jeffreys, F.R.S., author of the following papers which have appeared in the *Journal* during 1924-1927:—

(1) "The cause of cyclones."
(2) "On fluid motions produced by differences of temperature and humidity."
(3) "On the dynamics of geostrophic winds."
(4) "Cyclones and the general circulation."

The Howard Prize, consisting of an aneroid barometer suitably inscribed, was awarded to Cadet Philip Beeham, of H.M.S. "Worcester," for an essay on "The effect of prevailing winds on oceanic flights for aeroplane and airship over the North Atlantic Ocean in (*a*) temperate zone, (*b*) tropic zone."

Prize Essay Scheme.—This scheme, which was referred to in last year's Report, was carried through satisfactorily and the following awards made:—1st Prize, Mr. Ewart Walsh; 2nd Prize, Mr. R. Phillips; 3rd Prize, Mr. C. H. Belshaw. The Council are indebted to Mr. B. C. Wallis for kindly adjudicating on the essays. His report and the winning essays will be found in the October *Journal*.

LECTURES.—The lectures given under the Council's lecture scheme were highly successful, and the Council desire to place on record their appreciation of the services of the lecturers. The demand for such lectures is very great and it is hoped that it may be possible to make a further grant for this purpose.

BROADCASTING AND WEATHER.—In response to an inquiry from the British Broadcasting Corporation as to the scientific basis for the alleged effect of broadcasting in causing rainy weather, an authoritative statement was drawn up, showing that there was no basis for such an effect, and was sent to the B.B.C. This was published in the *Radio Times* for June 29th, and attracted some notice in the Press. The statement is reprinted in the *Journal*, p. 260. The incident is small in itself, but is of interest as an indication of the way in which the Society can at times perform an important public service by promoting a sane outlook in matters of weather.

APPENDIX

STATEMENT OF RECEIPTS AND PAYMENTS

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance from 1927—Cash at Bank of England	366	18	2			
Deposit at Westminster Bank	300	0	0			
				666	18	2
Subscriptions for 1928	1448	3	1			
,, ,, former years	115	18	0			
,, ,, 1929	50	6	0			
				1614	7	1
Life Compositions				35	0	0
Entrance Fees				43	1	0
Dividends and Interest				43	11	2
Sale of Publications, Advertisements, etc.				333	5	11
Rent of Maisonette				225	0	0
Contribution for administrative purposes from British Rainfall Organization Fund				10	0	0
Contributions from Fellows to the Journal Fund				125	0	0
Contribution from the Government Publication Grant, in aid of publications				100	0	0
				£3196	3	4

'OR THE YEAR ENDING DECEMBER 31, 1928.

PAYMENTS.

	£	s.	d.	£	s.	d.
ebentures—						
Redemption of six Debentures	300	0	0			
Interest paid on Debentures	78	0	0			
				378	0	0
ournal, etc.—						
Quarterly Journal, Nos. 224-227	383	16	3			
Illustrations	73	3	10			
Reprints of Papers	65	12	9			
Reviews	11	12	6			
Journal Index, 1901-1925	87	0	0			
Memoirs, Nos. 12-20	222	5	2			
Assistance in preparation of publications	80	0	0			
Bibliography of Meteorological Literature, Nos. 13 and 14	72	10	0			
Monthly Weather Reports, 1927	20	13	1			
				1016	13	7
'rinting, etc.—						
General Printing	56	15	0			
Stationery	37	4	0			
Books and Bookbinding	15	12	3			
				109	11	3
ffice Expenses, etc.—						
Salaries and Insurance	588	5	8			
Caretaker and Insurance	66	10	4			
Postage	115	2	1			
Telephone Charges	10	17	0			
Auditing Accounts for 1927	10	10	0			
Furniture and Repairs	12	7	6			
Petty Expenses	15	5	5			
				818	18	0
Coals, Lighting, Insurances, etc.—						
Coal and Coke	20	16	8			
Lighting	12	11	8			
Water Rate	6	10	0			
Insurance	13	12	0			
				53	10	4
Miscellaneous Expenditure—						
Essay Competition Prizes	10	0	0			
Howard Prize	2	2	0			
Expenses in connection with Museum	3	0	0			
Agent's Fee *re* Maisonette	5	5	0			
Lecture Expenses	17	5	11			
				37	12	11
Meetings—						
Meeting Expenses, Refreshments, Crockery, etc.	29	9	6			
				29	9	6
Balance—						
Cash at Bank of England	452	7	9			
Cash on Deposit at Westminster Bank	300	0	0			
				752	7	9
				£3196	3	4

Examined, compared with vouchers, and found correct.

BALL, BAKER, ASH & CO.,
Chartered Accountants.

FINSBURY COURT, FINSBURY PAVEMENT,
LONDON, E.C.2.
8*th January*, 1929.

APPENDIX

ASSETS AND LIABILITIES,

LIABILITIES.

	£	s.	d.	£	s.	d.
Subscriptions paid in advance	50	6	0			
Electric Light	2	8	9			
Quarterly Journal, No. 228	82	8	4			
Memoirs, Nos. 21 and 22	52	15	3			
Monthly Weather Reports, 1928, estimated at	22	0	0			
				209	18	4

5% Debentures.

	£	s.	d.	£	s.	d.
Authorised.—160 Debentures of £50 each charged on all the property of the Society, both present and future ...	£8000	0	0			
Issued.—As at 31st December, 1927, 42 Debentures	2100	0	0			
Less.—Six Debentures cancelled during the year	300	0	0			
				1800	0	0
Excess of Assets over Liabilities*				5409	12	0
				£7419	10	4

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* This excess is exclusive of the value of the Library and Stock of Publications.

I.—continued

DECEMBER 31, 1928.

ASSETS.

	£	s.	d.	£	s.	d.
New South Wales 4 per cent. Inscribed Stock, 1933, £649 1s. 7d. @ 93	603	12	10			
Funding Stock, 4 per cent., 1960-1990, £200 @ 90	180	0	0			
				783	12	10

Note.—The above Stocks are valued at prices estimated by the Society's Broker.

	£	s.	d.	£	s.	d.
Subscriptions unpaid, amounting to £260, estimated at	80	0	0			
Entrance Fees unpaid	8	8	0			
Interest due on Stock, estimated at	14	0	0			
				102	8	0
Furniture, Fittings, etc.	346	16	9			
Instruments	59	5	0			
Estimated value of Society's house, 49, Cromwell Road ...	5375	0	0			
				5781	1	9
Cash at Bank of England	452	7	9			
Cash on Deposit at Westminster Bank	300	0	0			
				752	7	9
				£7419	10	4

Examined and Securities seen.

BALL, BAKER, ASH & CO.,

Chartered Accountants.

8th *January*, 1929.

APPENDIX

BRITISH RAINFALL ORGANIZATION FUND,

RECEIPTS.

	£	s.	d.	£	s.	d.
Balance from 1927—Cash at Bank of England	35	9	2			
Deposit at Westminster Bank	50	0	0			
				85	9	2
Rent of 62, Camden Square				60	0	0
Dividends and Interest				77	7	1
Repayment of £50 National War Bonds, 1928				52	10	0
Sales of *Rainfall Atlas*				38	1	9
				£313	8	0

SYMONS MEMORIAL FUND,

RECEIPTS.

	£	s.	d.
Balance from 1927—Cash at Bank of England	37	4	11
Interest received on Investments	21	10	6
	£58	15	5

DINES MEMORIAL FUND (formerly

RECEIPTS.

	£	s.	d.
Balance, January 1st, 1928—Cash at Bank of England	26	6	4
Dividends and Interest	10	0	4
Contributions from Fellows	102	9	3
	£138	15	11

I.—*continued*

DECEMBER 31, 1928.

PAYMENTS.

	£	s.	d.	£	s.	d.
Payment to Observers				36	0	0
Ground Rent, 62, Camden Square				6	0	0
Insurance				1	7	0
Permanent Register for Observations				7	5	0
Sundries and Repairs during year				5	5	1
Postage, *Rainfall Atlas*				1	9	1
Administrative Expenses, transferred to Society's General Account				10	0	0
Purchase of £100 5 per cent. War Stock, 1929-47				103	4	9
				170	10	11
Balance—Cash at Bank of England	42	17	1			
Deposit at Westminster Bank	100	0	0			
				142	17	1
				£313	8	0

Note.—The Society holds on account of this Fund £2,151 London and North-Eastern Railway 3 per cent. Debenture Stock, £123 5s. New South Wales 3 per cent. Inscribed Stock, £400 5 per cent. War Stock, 1929-47.

Examined and found correct.

BALL, BAKER, ASH & CO.,
Chartered Accountants.

8th January, 1929.

DECEMBER 31, 1928.

PAYMENTS.

	£	s.	d.
Gold Medal, 1928	26	0	0
Symons Memorial Lecture	10	10	0
Balance—Cash at Bank of England	22	5	5
	£58	15	5

Note.—The Society holds on account of this Fund £700 Cardiff Corporation Redeemable Stock, 3 per cent., and £123 8s. 8d. 4 per cent. Consolidated Stock.

Examined and found correct.

BALL, BAKER, ASH & CO.,
Chartered Accountants.

8th January, 1929.

RESEARCH FUND), DECEMBER 31, 1928.

PAYMENTS.

	£	s.	d.
Balance, December 31st, 1928—Cash at Bank of England	138	15	11
	£138	15	11

Note.—The Society holds on account of this Fund £85 9s. 1d. Consols, and £157 15s. 11d. 5 per cent. War Stock, 1929-47.

Examined and found correct.

BALL, BAKER, ASH & CO.,
Chartered Accountants.

8th January, 1929.

APPENDIX II.

DONORS TO THE LIBRARY DURING THE YEAR 1928.

1. INSTITUTIONS.

Aberystwyth, Geographical Association.
Alnwick, Berwickshire Naturalists Club.
Angora, Institut Météorologique.
Apia Observatory, Samoa.
Athens, Observatoire National.
Azerbaidjan, Service Météorologique.
Azores, Service Météorologique.

Bangalore, Mysore Government.
Bangkok, Royal Irrigation Department.
Barbados, Colonial Secretary's Office.
Barcelona, Institut d'Estudis Catalana.
Barcelona, Servei Meteorologic de Catalunya.
Batavia, Royal Magnetical & Meteorological Observatory.
Beira, Observatorio Meteorologico.
Belgrade, Observatoire Météorologique.
Bengal, Government Irrigation Department.
Bergen, Geofysiske Institut.
Berkeley, University of California.
Berlin, Deutsche Meteorologische Gesellschaft.
Berlin, Preussische Meteorologische Institut.
Bourges, Observatoire.
Bremen, Landeswetterwarte.
Brussels, Académie Royale de Belgique.
Brussels, Institut Royal Météorologique de Belgique.
Brussels, Ministère des Colonies.
Brussels, Société Belge d'Astronomie.
Brighton and Hove Natural History Society.
Bucharest, Institutul Meteorologic Central al Romaniei.
Bucharest, Observatoire Astronomique et Météorologique.
Budapest, Hungarian Meteorological Society.
Buenos Aires and Cordoba, Oficina Meteorologica Argentina.

Cairo Ministry of Public Works, Physical Department.
Calcutta, Indian Association for Cultivation of Science.
Calcutta and Poona, India Meteorological Department.
Cambridge, Mass., Harvard College Observatory.
Cambridge, Philosophical Society.
Cambridge, Solar Physics Observatory.
Cape Town, Royal Society of South Africa.
Cashel, Irish Rainfall Association.
Christ's Hospital, West Horsham, Natural History Society.
Coimbra, Observatorio Meteorologico e Magnetico.
Colombo Observatory.
Copenhagen, Dansk Meteorologisk Institut.
Cordoba (Arg.), Academia Nacional de Ciencias.
Coventry, City Medical Department.
Cyprus, Office of Public Works.

Darmstadt, Landesamt für Wetter- und Gewässerkunde.
Davos, Meteorologische Station.
Dresden, Sächsische Landeswetterwarte.
Dublin, Royal Dublin Society.
Dublin, Royal Irish Academy.

Eastbourne, City Medical Department.
Edinburgh, General Register Office.
Edinburgh, Royal Observatory.
Edinburgh, Royal Scottish Geographical Society.
Edinburgh, Royal Society.

Falmouth Observatory.
Falmouth, Royal Cornwall Polytechnic Society.
Felstead School Scientific Society.

Geneva, Société de Géographie.
Genoa, R. Institute Idrografico.
Glasgow, Royal Philosophical Society.
Granada, Observatorio de Cartuja.
Greenwich, Royal Observatory.
Grenada, Colonial Secretary's Office.
Guernsey, States Meteorological Station.

Halle, K. D. Akademie der Naturforscher.
Hamburg, Deutsche Seewarte.
Harpenden, Rothamsted Experimental Station.
Havana, Secretaria de Agricultura, Commercio y Trabajo.
Helsingfors, Hydrografiska Byran.
Helsingfors, Merentutkimuslaitos.
Helsingfors, Meteorologische Zentralanstalt des Finnischen Staates.
Helsingfors, Societas Scientiarum Fennica.
Hongkong, Royal Observatory.

Irkutsk, Observatoire Magnétique et Météorologique.

Jamaica, Government Meteorologist.

Kiev, Service Météorologique de l'Oukraine.
Kôbe, Imperial Marine Observatory.

Leipzig, Geophysikalische Institut.
Lemberg, Observatorium der technischen Hochschule.
Leningrad, Central Geophysical Observatory.
Leningrad, Hydrological Institute.
Leningrad, Russian Geographical Society.
Lindenberg, Preussische Aeronautische Observatorium.
Lisbon, Observatorio Central Meteorologico.
Lisbon, Sociedad de Geographia.
Liverpool, Engineering Society.
Ljubljana, Institut Météorologique et de Géodynamique.
London, Admiralty, Hydrographic Department.
London, Air Ministry, Meteorological Office.
London, British Association Advancement Science.
London, Dept. Sci. and Industrial Research.
London, General Register Office.
London, Geological Society.
London, Institution of Aëronautical Engineers.
London, Institution of Electrical Engineers.
London, Institution of Sanitary Engineers.
London, Institution of Water Engineers.
London, International Society of Medical Hydrology.
London, Ministry of Agriculture.
London, Physical Society.
London, Royal Aëronautical Society.
London, Royal Agricultural Society.
London, Royal Astronomical Society.
London, Royal Botanic Society.
London, Royal Geographical Society.
London, Royal Institution of Great Britain.
London, Royal Sanitary Institute.
London, Royal Society.
London, Royal Society of Arts.
London, Royal Statistical Society.

Madrid, Instituto Geografico y Estadistico.
Madrid, Real Sociedad Geografica.
Madrid, Sociedad Española de Meteorologia.
Manchester, Literary and Philosophical Society.
Manchester, Municipal College of Technology.
Manila, Weather Bureau.
Marlborough College Natural History Society.
Marseille, Com. Météor. Départe. des Bouches-du-Rhône.
Mauritius, Royal Alfred Observatory.
Melbourne, Commonwealth Weather Bureau.
Mexico, Secretaria de Agricultura y Fomento.
Mexico, Sociedad Cientifica " Antonio Alzate."
Middlesbrough, Albert Park Observatory.
Milan, R. Osservatorio Astronomico de Brera.
Mizusawa, Japan, International Latitude Observatory.
Modena, Observatorio Geofisico.
Moscow, Commission Actinométrique Permanente.
Munich, Bayerische Landeswetterwarte.

Nairobi, Kenya, Dept. of Agriculture.
Newport, Isle of Wight Natural History Society.
New York, American Association of Petroleum Geologists.
New York, American Geographical Society.
New York, Central Park Observatory.
Nottingham City Council.

Odessa, Observatoire Géophysique.
Omsk, Siberian Academy of Agriculture and Forestry.
Oslo, Geophysical Commission.
Oslo, Norsk Meteorologisk Institut.
Ottawa, Dominion Observatory.
Ottawa, Royal Society of Canada.
Ottawa, Seismological Society of America (E. Section).
Oxford, Radcliffe Observatory.

Pahang, F. M. S. Administration.
Panama, Isthmian Canal Commission.
Paris, Office National Météorologique de France.
Paris, Service Météorologique de la Ville de Paris.
Paris, Service Technique d'Hygiène.
Paris, Société de Géographie.
Paris, Société d'Océanographie de France.
Perth, Western Australia, Government Statistician's Office.
Philadelphia, American Philosophical Society.
Phu-Lien, Observatoire Central.
Port-au-Prince, Observatoire Météorologique du Séminaire-College St. Martial.
Port Moresby, Papua, Government Secretary's Office.
Porto Alegre, Instituto Astronomico e Meteorologico.
Portsmouth Medical Department.
Prague, Institut Météorologique de la République Tchécoslovaque.
Pretoria, Meteorological Office.

Reykjavik, Vedurstofan.
Rhodesia, Southern, Agricultural Dept.

Rio de Janeiro, Directoria de Meteorologia.
Rome, International Institute of Agriculture.
Rome, Ministero Aeronautica, Ufficio Presagi.
Rome, Ministero dei Lavori Pubblici.
Rome, Reale Società Geografica Italiana.
Rome, R. Ufficio Centrale di Meteorologia e Geofisica.
Rome, Società Sismologica Italiana.

San Juan, Porto Rico, West Indian and Caribbean Service.
San Sebastian, Observatorio de Igueldo.
Santiago de Chile, Observatorio de "El Salto."
St. Lucia, Government Office.
St. Lucia, Castries Botanical Station.
Southampton, Ordnance Survey.
Southport, Fernley Observatory.
Stockholm, Abisko Naturvetenskapliga Station.
Stockholm, Hydrografiska Byrån.
Stockholm, Statens Meteorologisk-Hydrografiska Anstalt.
Stockholm, Svenska Hydrografiska-Biologiska Kommission.
Stonyhurst College Observatory.
Strasbourg, Central Bureau Sismologique Française.
Strasbourg, Institut de Physique du Globe.
Subiaco, Osservatorio Geofisico di Montecassino.
Sucre, Bolivia, Observatorio de la Compañia de Jesus.
Suva, Fiji, Harbour Master's Office.
Sydney, N.S.W., Royal Society.

Tacubaya, Servicio Meteorologico Mexicano.
Talance, Observatoire de Gironde.
Tashkent, Université de l'Asie Centrale.
Tateno, Japan, Aerologia Observatorio.
Teddington, National Physical Laboratory.
Tiflis, Geophysical Observatory, Georgiens.
Tokyo, Central Meteorological Observatory.
Tokyo, Imperial Earthquake Investigation Committee.
Tokyo, Imperial University.
Tokyo, Meteorological Society of Japan.
Tokyo, National Research Council of Japan.
Toronto, Meteorological Office.
Toronto Observatory.
Torquay, Borough Observatory.
Tortosa, Observatorio del Ebro.
Tripoli, R. Ufficio Meteorologica.
Tsingtao Observatoire.
Tunis, Service Météorologique.
Turin, Società Meteorologica Italiana.

Upsala, Observatoire Météorologique de l'Université.
Utrecht, K. Nederlandsch Meteorologisch Instituut.

Valencia, Federacion Agraria de Levante.
Venice, Ufficio Idrografico R. Magistrato delle Acque.
Venice, Union Géodesique et Géophysique Internationale.
Vienna, Sonnblick Verein.
Vienna, Zentralanstalt für Meteorologie und Geodynamik.
Vladivostok, Observatoire Géophysique Centrale.

Warsaw, Institut Météorologique de Pologne.
Washington, Carnegie Institution.
Washington, Hydrographic Office.
Washington, National Academy of Sciences.
Washington, Smithsonian Institution.
Washington, U.S. Coast and Geodetic Survey.
Washington, U.S. Weather Bureau.
Wellington, N.Z., Census and Statistics Office.
Wellington, N.Z., Dominion Meteorological Office.
Wellington, N.Z., New Zealand Lands and Surveys.
Worcester, Mass., American Meteorological Society.

Yorkshire Philosophical Society.

Zi-Ka-Wei, Observatoire Magnétique, Météorologique et Sismologique.
Zinsen, Meteorological Observatory Tyôsen.
Zomba, Meteorological Department.
Zürich, Schweizerische Meteorologische Zentral-Anstalt.

2. INDIVIDUALS, PUBLISHERS, ETC.

Philip Allan & Co.
Prof. J. Bartels.
Dr. F. Baur.
J. Baxendell.
F. A. Bellamy.
Ernest Benn, Ltd.
Louis Besson.
S. Morris Bower.
Rev. H. H. Breton.
C. E. P. Brooks.
Cambridge University Press.
C. F. Casella & Co.
Dr. C. Chree (the late).
Christopher Publishing House, Boston, U.S.A.
Dr. Vaughan Cornish.
J. W. de Graft Johnson.

J. I. de Jongh.
M. Doporto.
J. Dover.
C. Easton.
J. Engelhorn.
Prof. F. Eredia.
R. Esnault-Pelterie.
H. v. Ficker.
I. V. Figourovsky.
Gauthier-Villars, et Cie.
J. Glaisyer.
A. H. R. Goldie.
Henri Grand.
Sir Richard Gregory.
F. Groissmayr.
Dr. G. Hellmann.
Miss A. M. Hodgkin.
N. Holden.
D. W. Horner.
R. E. Horton.
J. Hunter.
Dr. H. E. Hurst.
H. Jameson.
A. Kephala.
Dr. E. Kidson.
Dr. F. Klute.
Dr. K. Knoch.
Emile Larose (Librarie).
G. C. Lawson.
Dr. A. F. Lebedeff.
Dr. F. Lindholm.
Macmillan & Co.
Miss C. Marshall.
Capt. W. N. McClean.
H. Mémery.
Asche Moe.
Messrs. Nitram, Ltd.
R. Oldenbourg.
Oxford University Press.
W. H. Pickering.
A. W. Preston.
P. Rintoul.
Rochester, N.Y., Taylor Instrument Co.
J. Rouch.
W. B. Schostakowitsch.
T. J. J. See.
Dr. W. H. Seymour.
Sir Napier Shaw.
Ernesto Sifontes.
Dr. G. C. Simpson.
Lt.-Col. T. C. Skinner.
Dr. Elmer A. Smith.
Georg Stilke.
S. Suzuki.
John Taylor & Sons.
L. D. Vaughan.
J. Vincent.
R. de C. Ward.
Erich Wasmund.
L. Weickmann.

The Editors of—
Nature.
Observatory.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

January 16, 1929.

At the *Ordinary Meeting* the following were balloted for and elected Fellows of the Society:—

Joseph William De Graft Johnson, D.C.L., F.R.C.I., 13, Highbury Terrace, N. 5;
Alfred George Glenn, 46, Sidegate Lane, Ipswich, Suffolk;
Walter John Glenn, 46, Sidegate Lane, Ipswich, Suffolk;
David Peter, B.A., Alleyne's Grammar School, Stone, Staffs.;

Lieut.-Colonel E. Gold, D.S.O., F.R.S., gave a brief account of the heavy snow-squall which passed over London about 9 a.m. on that morning (see p. 196).

February 20, 1929.

At the *Ordinary Meeting* the following were balloted for and elected Fellows of the Society:—

Prof. Dr. Julius Bartels, Meteorologisches Instituts der Forstlichen Hochschule, Eberswalde, Germany;
K. P. Ghose, Student, Imperial College of Science and Technology, South Kensington.

Mr. C. K. M. Douglas gave an informal talk on the recent cold spell as experienced in this country and on the continent (see p. 199).

January 16, 1929.

Annual General Meeting.

Sir Richard Gregory, D.Sc., President, in the chair.

Dr. J. Glasspoole and Mr. N. Lang Smith were appointed scrutineers of the ballot for the Council.

The adoption of the Report of the Council, which was in the hands of the Fellows present, was proposed by the President. The meeting then resolved " That the Report of the Council be received and adopted and that it be printed in the *Quarterly Journal.*

It was proposed by Mr. C. J. P. CAVE, seconded by Captain Sir DAVID BARKER, and resolved " That the thanks of the Society be given to the Council for their services during the past year." The President briefly acknowledged the vote of thanks.

The Buchan Prize for 1929, awarded to Dr. HAROLD JEFFREYS, was presented to him by the President, after he had referred to Dr. Jeffreys's contribution to meteorological research (see page 191). Dr. Jeffreys briefly expressed his thanks for the honour conferred on him.

The President then delivered an address on " Amateurs as Pioneers " (see p. 103). At the conclusion of the address it was proposed by Sir GILBERT WALKER, seconded by Prof. S. CHAPMAN, and resolved " That the thanks of the Society be given to Sir Richard Gregory for his services as President during the past year, and for his address, and that he be asked that the address may be printed in the *Quarterly Journal.*"

The Scrutineers then declared the following to be the Officers and Council for the ensuing year :—

PRESIDENT.

Sir RICHARD GREGORY, D.Sc., LL.D., F.R.A.S.

VICE-PRESIDENTS.

ROWLAND ARNISON, A.Inst.P., F.R.G.S.
Lieut.-Colonel ERNEST GOLD, D.S.O., F.R.S.
IVAN DONALD MARGARY, M.A., F.R.G.S.
ROBERT ALEXANDER WATSON WATT, B.Sc., A.M.I.E.E.

TREASURER.

FRANCIS DRUCE, M.A., F.L.S..

SECRETARIES.

CHARLES ERNEST PELHAM BROOKS, D.Sc.
Commander L. G. GARBETT, R.N., F.R.G.S.
A. CRICHTON MITCHELL, D.Sc., F.R.S.E.

FOREIGN SECRETARY.

R. G. K. LEMPFERT, C.B.E., M.A., F.Inst.P.

COUNCILLORS.

ERNEST GEORGE BILHAM, A.R.C.Sc., B.Sc.
Rev. HAROLD BUCKTON.
Mrs. C. J. P. CAVE.
LEWEN HENRY GEORGE DINES, M.A.
GEORGE MILLER BOURNE DOBSON, M.A., D.Sc., F.R.S.
CHARLES KENNETH MACKINNON DOUGLAS, B.A.
FRANK ENTWISTLE, B.Sc.
JAMES FAIRGRIEVE, M.A., F.R.G.S.
RICHARD MARSHALL, F.R.A.S.
JOHN SWITZER OWENS, M.D., B.A.
Commander ERNEST CLAUDE SHANKLAND, R.N.R.
WILLIAM MOODY WITCHELL, B.Sc., F.R.A.S.

BUCHAN MEMORIAL PRIZE 1929.

PRESENTATION TO DR. HAROLD JEFFREYS, F.R.S.

The presentation of the Buchan Memorial Prize was made at the Annual General Meeting of the Society on January 16.

The prize is awarded biennially to the author of those papers printed in the last four [in future five] volumes of the *Quarterly Journal,* which are adjudged as containing the most important original contributions to meteorology. The papers by Dr. Jeffreys for which the prize is awarded are as follows:—

1. "The cause of cyclones." Vol. 50, 1924. Pp. 51-67;
2. "On fluid motions produced by differences of temperature and humidity." Vol. 51, 1925. Pp. 347-356;
3. "On the dynamics of geostrophic winds." Vol. 52, 1926. Pp. 85-101;
4. "Cyclones and the general circulation." Vol. 53, 1927. Pp. 401-405.

In presenting the prize, the PRESIDENT (Sir Richard Gregory) read the following:—

The Circulation of the Atmosphere.

The gradual building up of a working model of the mechanism of the winds is an interesting example of the convergence of two lines of reasoning, originally poles asunder, until they met and supplemented each other. These two lines of reasoning are the thermodynamics of the air and the dynamics of winds.

Thermodynamics is the older by a few years, for Boyle's law of the relation of volume to pressure and temperature was formulated in 1662, as a result of his experiments at Oxford "touching the spring of air." The explanation of the cooling of air dynamically by ascent and consequent decrease of pressure did not follow, however, for more than a century, being apparently due to John Dalton in a paper published in 1800 "On experiments and observations on the Heat and Cold produced by the mechanical condensation and rarefaction of air." Dalton also investigated the physics of a mixture of air and water vapour, and so laid the basis of a very large part of modern meteorology.

The dynamics of winds began in a much more speculative way. As soon as the existence of the trade winds and monsoons became generally known, attempts were made to explain them. Edmund Halley, the astronomer, made the first serious attack on the problem in a paper, published in the *Philosophical Transactions* for 1686, entitled "An historical account of Trade Winds and Monsoons observable in the seas between and near the Tropics with an attempt to assign the physical causes of the said winds." This, the beginning of dynamical meteorology, was an attempt to connect the general circulation of the atmosphere with the distribution of the sun's heat over the surface of the earth. Halley's work, however, failed to account for the east-west component of air movement. George Hadley in 1735 introduced the effect of the earth's rotation, and so laid the basis of the modern theory of the winds. Hadley's explanation took account of the deflecting force on north and south winds only; the extension of the theory to all winds was a development of the nineteenth century, due especially to Ferrel. Until it was re-discovered by John Dalton in 1793, Hadley's deflecting force was forgotten, while Halley's crude theory received general acceptance.

The collection of facts went on independently of theorising. The first adequate description was written by William Dampier, a buccaneer, who in 1697 published his "Voyage round the World," containing a "Discourse on Winds," which remained authoritative for a century. Dampier's work also gave the first description of a typhoon. The foundations of our modern knowledge were laid down by M. F. Maury, an American naval officer, who in 1839, at the age of 33, met with an accident which rendered him unfit for active service, after which he distributed to captains of vessels specially prepared log books and collected observations of winds and currents. He embodied these in his work, "The Physical Geography of the Sea," London, 1855. He realised, however, that international co-operation was necessary for the progress of ocean meteorology, and secured an international conference at Brussels in 1853.

The first really satisfactory charts of winds (and isobars) over the world were, however, compiled by Alexander Buchan, in his famous "Report on Atmospheric Circulation," which forms part 5 of volume 2 of the Report on the voyage of H.M.S. *Challenger*, 1873-76. Charts of temperature were also included. Buchan's charts were the basis of the "Atlas of Meteorology" which formed volume III. of Bartholomew's Physical Atlas, and remained the standard meteorological atlas until the publication in 1928 of volume 2 of Sir Napier Shaw's "Manual of Meteorology."

Our knowledge of the structure of tropical revolving storms is generally attributed to William C. Redfield, Major-General W. Reid, and Henry Piddington, but hurricanes had been described as whirlwinds by Varenius as early as 1650, and in 1698 Captain Langford contributed to the Royal Society an account, published in the *Philosophical Transactions*, of five hurricanes, the last of which he had successfully forecast some days in advance, giving instructions which saved a British squadron. Redfield (1831) constructed synoptic charts, with the barometer reduced to sea level, which enabled him to define a cyclone as a large mass of air with a rapid motion of rotation counter-clockwise, a calm centre and a motion of translation; he also recognised a "vorticose convergence" of the air and traced the paths with their recurvature. Reid (1846) gave the rules for manœuvring ships to avoid the "dangerous semi-circle," and in 1847 established warning signals at Barbados, based on a self-recording barometer. Piddington's first description of a hurricane in the Bay of Bengal appeared in 1839, and the first edition of the famous work "The Sailors' Horn-Book for the Law of Storms" appeared in 1854. Piddington described the incurvature of the winds and also introduced the term "cyclone." Piddington's work was continued and amplified by Charles Meldrum. Far less well known than Piddington or Reid, was Father Faura, of the Society of Jesus, a religious order that has had many men devoted to science. Father Faura in 1865 founded the Manila Observatory, and on July 7, 1879, predicted the approach of a typhoon which would pass over North Luzon. The event justified his warning. Shipping in the China Seas owes much to the Jesuit Fathers of both Manila and Shanghai, but this was the first time that the existence, duration and course of a typhoon had been predicted. Faura's work was undertaken entirely as an amateur, but so important were his predictions that directly cable connection existed the merchants of Hong Kong asked for reports to be sent them; in 1884 the Spanish Government raised his Observatory to the position of a Government establishment, and since 1901 the observations have been extended under the Philippine Weather Bureau of the United States Government.

The first series of synoptic charts for temperate latitudes was constructed by H. W. Brandes for the year 1783, and described in his "Beiträge zur Witterungskunde" in 1820. The charts themselves were not published, and have been lost, but a specimen chart was reconstructed by Hildebrandsson. His final conclusions on the subject of barometeric depressions were that a cyclonic storm arises from air breaking through into a vacuum, or rushing towards regions occupied by rarefied air, and that a depression advances from west to east above the earth's surface.

Brandes' conclusions were elaborated by the American J. P. Espy, in his "Philosophy of Storms," 1841. Espy's importance lies in his application to meteorology of the writings of John Dalton referred to above. He attributed the low pressure within a depression to the high temperature, which was maintained by the condensation of water vapour to form rain. Conversely an anticyclone is a region of descending and warming air in which no rain can fall. This theory held the ground until the close of the last century, when it was superseded by the picture of a depression drawn by W. H. Dines. Ballon-sonde ascents had shown that in this country at least the air in a depression is cold in the troposphere, while that in an anticyclone is warm. These relationships are reversed in the stratosphere (the stratosphere was discovered by Teisserenc de Bort in 1899), where the depression is warm and the anticyclone cold, and the pressure at the surface is accordingly due to conditions in the stratosphere transmitted downwards through the troposphere.

In all these investigations depressions or cyclones had been treated as isolated phenomena, quite independent of the general circulation. So early as 1828, however, H. W. Dove had related barometric depressions to the general circulation. Dove regarded the general circulation very much as Bjerknes did, as made up of an equatorial current and a polar current, the changes of weather in temperate latitudes being merely incidents in the conflict of these two currents, which gyrate round one another to form cyclones. This was a wonderful generalisation to have been made before the era of regular daily synoptic charts. Although Dove attained great honour among meteorologists (especially for his charts of isotherms), this theory was too far in advance of its time.

The complexities revealed by daily synoptic charts in the last half of the nineteenth century seemed inconsistent with Dove's simple system. The beginnings of a new era were laid down by the research carried out by Sir Napier Shaw and Mr. R. G. K. Lempfert on "The Life History of Surface Air Currents" (1906) and by researches into line-squalls, and culminated in the theory of the polar front and the structure of depressions elaborated by V. and J. Bjerknes, father and son, and H. Solberg. J. Bjerknes and Solberg also related depressions to the general circulation of the atmosphere, but still rather as accidents than as an essential part.

Meanwhile, however, it had been found that an exchange of air across the parallels of latitude is in fact essential, and is caused partly at least by the friction of the moving air with the earth's surface, which results in turbulence.

The mathematical treatment of turbulence and diffusion was developed by G. I. Taylor and L. F. Richardson in this country, and by Akerblom, Hesselberg and Sverdrup, and W. Schmidt in Europe, and has apparently shown that there is an organic connection throughout the whole range of phenomena from minute distances up to thousands of kilometres. The whole circulation of the atmosphere may even be regarded as an example of diffusion on the grand scale. Finally, Dr. Harold Jeffreys completed the picture by demonstrating that "cyclones" in temperate latitudes were required on dynamical grounds to provide westerly winds to balance the easterly component of the wind in tropical and polar latitudes. This paper: "Cyclones and the general circulation" (*Quarterly Journal*, 1927) is one of the series for which Dr. Jeffreys has been awarded the Buchan prize, and contains the passage:

"Increase of temperature towards the equator implies that the velocity from the west must increase with height, and in these conditions it appears that frictional interaction between different layers of the air and between the lowest layer and the ground would suffice to destroy any motion symmetrical about the earth's axis. Irregular horizontal interchange of air must, therefore, be developed, and it seems that this implies a system of cyclones resembling in their main features those we know. One effect of the interchange would be that the normal winds at the surface must be on the whole as much easterly as westerly."

Dr. Jeffreys has applied mathematical physics to many difficult problems in the heavens and the earth, and has contributed notably towards their solution. To each subject studied by him he has brought original views and critical analysis; and his book upon "The Earth: its Origin, History, and Physical Constitution" represents the high standard of scientific exposition and insight which characterises all his work. From considerations of hypotheses as to the manner in which a fluid earth would solidify and afterwards cool to its present state, Dr. Jeffreys has proceeded to inquiries into the atmosphere around the solid crust, and has studied the mechanism and cause of cyclones and other aspects of fluid motion of significance to meteorological science or related geophysics. Whether dealing with the solid earth in connection with the nature of isostasy, with wave propagation, geostrophic winds, or atmospheric circulation, Dr. Jeffreys always succeeds in bringing ascertained knowledge in close contact with mathematical considerations and arriving at results of practical service as well as scientific value. The papers contributed by him to the *Quarterly Journal* of our Society are distinctive of his work as a mathematical physicist and meteorologist of leading rank, and the Society is both proud and glad to award him the Buchan Prize for this year in recognition of it.

Dr. JEFFREYS, in reply, said: I wish, in the first place, to thank the Society very deeply for the unexpected honour it has done me in awarding me the Buchan Prize, and its President for his kind remarks in presenting it. I hope, however, that nobody will go away with the idea that the problem of cyclones is solved. I think the outline of the solution has been obtained, but most of the details remain to be filled in, and I fear that the details will be harder to ascertain than the general scheme. I should like also to remind the Society that an essential part was played by Dr. Whipple in directing a timely criticism against a portion of the third paper, when progress seemed to be held up by a definite conclusion in doubtful agreement with the facts.

CORRESPONDENCE AND NOTES

Curious Ice Formation

Mr. E. Nimmo has forwarded the accompanying sketch (Fig. 1) of a curious ice formation which he observed on a pond in Broadstone, Dorset, on March 6. The pond had been covered with ice from 1½ to 4 inches thick for the previous three weeks. Mr. Nimmo says:—" After a comparatively warm day (maximum 48°F.) I visited it this evening and found that although the ice was still 1¾ inches thick, it gave way with the slightest push. On closer inspection I found it to be marked all over exactly like a honeycomb, except that the ' cells ' were irregular instead of hexagonal; pressure produced a clean cleavage along vertical surfaces, of which these honeycomb markings formed the ends. Further breakage in the hand reduced it to a number of little columns, each the full thickness of the ice (1¾ inches), with parallel sides and top and bottom bounded by one of the honeycomb ' cells.' "

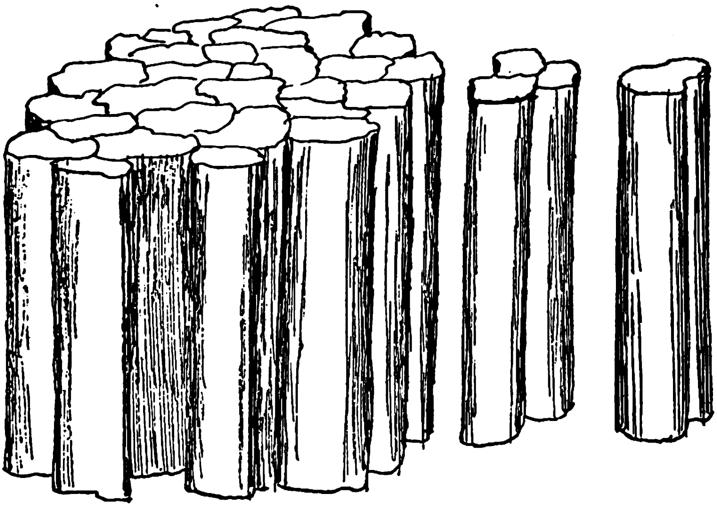

Fig. 1.—Formation of ice in thawing, Broadstone, Dorset, March 6, 1929 (natural size).
(From a sketch by E. Nimmo.)

" Exceptional Visibility " in relation to the Type of Air Prevailing

There is a widely held opinion that " exceptional visibility " may be found in polar air, but can never be found in tropical air, using the terms " polar air " and " tropical air " in the sense of the Bjerknes ideas of map analysis. H. C. Willett, in a recent important paper,[1] expresses this opinion by saying categorically:—"In no case whatsoever is tropical air accompanied by really good visibility." It was to combat this and similar statements that the present note was undertaken.

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[1] H. C. Willett, " Fog and Haze; their cause, distribution and forecasting." *Washington, Monthly Weather Review*, November, 1928.

Exceptional visibility may be defined as that peculiar type of visibility in which the atmosphere is remarkably and abnormally transparent, and in which distant objects stand out clearly and seem very close, this apparent closeness being perhaps the most striking characteristic. Such "exceptional visibility" is a comparatively rare phenomenon in the British Isles, and to investigate the conditions of its occurrence it became necessary to find a station that had kept a more or less continuous watch for it, and duly reported it, in accordance with the strict definition set out above. Such a station was found in Ross-on-Wye in Herefordshire for the period April 1st, 1927—March 31st, 1928.

The method employed in the investigation was as follows. The charts issued daily by the Geophysical Institute at Bergen, Norway, based upon observations at 7h. G.M.T., have the types of the air streams marked upon them, and thus an examination of them from day to day enabled the type of air at Ross-on-Wye, at any given time during the period in question, April 1st, 1927—March 31st, 1928, to be determined. Any occasion of "exceptional visibility" reported from Ross could thus be allocated to a given type of air.

Forty-eight cases of "exceptional visibility" were found, and their allocation among the types of air is shown below, "summer" being taken as the months April to September (both inclusive), and "winter" as the months October to March. The remaining "Bjerknes air types" not mentioned either did not occur at Ross-on-Wye during the period, or, if occurring, were not accompanied by "exceptional visibility."

Number of cases of exceptional visibility.

Maritime polar air	24 in summer,	9 in winter.
Genuine polar air	4 ,,	1 ,,
Sinking polar air	3 ,,	0 ,,
Sinking maritime polar air ...	1 ,,	0 ,,
Returning polar air	1 ,,	0 ,,
Tropical air	4 ,,	1 ,,

Of the 48 cases of "exceptional visibility," 43 occurred in some variety of polar air. This is a high proportion, but the fact that the remaining five occurred in tropical air is sufficient to show Willett's statement that "in no case whatsoever is tropical air accompanied by really good visibility" to be unsound. Or to put the matter in another way, polar air cannot be held to be the sole environment for "exceptional visibility."

W. H. Pick.
March 15, 1929. D. E. Davies.

Remarkable Snowfall in London

Colonel Gold, at the request of the President, gave a brief account of a short but heavy snowstorm which passed across London on the morning of January 16. Slight or moderate snow had been falling for some time when relatively suddenly the sky became practically dark, and for a few minutes snow fell very heavily and was accompanied by gusts of wind which filled the air with powdery snow from the roofs of the houses. The degree of darkness varied in different places: in some places it was as dark as night. The storm ended comparatively suddenly, and the light returned.

When Dr. Owens asked him just before the meeting what was the cause of the phenomenon, he had described it as a "cold front," but it was not the simple cold front of the squall line of the orthodox depression. It was rather analagous to one type of summer thunderstorm. That morning there was a great Northerly current extending from Scandinavia right down the British Isles and North Sea, across France as far as Spain. The air in this current was cold both at the surface and in the upper air. Differences of temperature were developed in the current as it moved southwards, more particularly by the effect of the North Sea. These differences of temperature in association with the low upper air temperature produced instability, and the development of the thunderstorm type of squall. In front of the squall the air rushed upwards, probably to very great heights, the water vapour in it condensed and produced a cloud of great vertical thickness. It was this cloud which caused the darkness, and not, as was so frequently the case on occasions of darkness in London in the daytime, an accumulation of London fog in almost stationary air.

Naturally there was not enough information available to establish with certainty the identity of the storm over great distances. It appeared probable, however, that it had travelled from north to south at something like 40 miles an hour. At Cranwell, near Lincoln, there was heavy snow at 7 a.m.; at Cardington, near Bedford, a squall with heavy snow was reported at 7.50 a.m.; at Golders Green the storm occurred between 8.30 and 8.45 a.m.; at the Air Ministry in Kingsway, London, the time was exactly 8.45 a.m. and the great darkness lasted two minutes, from 8.45 to 8.47. At Teddington the heavy snow came at exactly 9 a.m., but there was no great darkness: at Merton Park it occurred between 9 and 9.10 a.m. and the darkness was intense; at Reigate it occurred about 9.15 a.m. and it reached Hastings about 11 a.m.

The occurrence of the storm was marked not only by darkness but by a sudden and considerable fall of temperature of about 3° or 4°F. At Cranwell the temperature at 7 a.m. was 29°F., while at 10 a.m. it was only 23°F.

(" Miss Austin informed me subsequently that at Bromley the storm occurred certainly before 8.45 a.m. and this agrees with the report from Purley of a storm at about 8.45 a.m. These reports indicate that this must have been a second storm distinct from the one which passed over the Air Ministry at 8.45 a.m."—E.G.).

Diurnal Variation of Pressure and Temperature at Aberdeen 1871-1926

The accompanying table gives the values of the constants in the harmonic series expressing the diurnal variation of pressure and temperature at Aberdeen Observatory for the period from January 1, 1871, to December 31, 1926. The data have been extracted from the *British Meteorological and Magnetic Year Book*, Part IV, for 1916-21, and the *Observatories' Year Book* for 1922-26, to which publications reference may be made for details as to methods of observation and reading of the autographic records. The geographical co-ordinates involved are :— Latitude, 57°10'N.: longitude, 2°6'W.: height of barometer cistern

DIURNAL VARIATION OF PRESSURE AND TEMPERATURE AT ABERDEEN, 1871–1926.

Constants in the Harmonic Series $c_0+\sum c_n \sin(15nt+a_n)$.

Month.	Pressure.									Temperature.								
	Mean.	Amplitudes.				Phase Angles (L.A.T.).				Mean.	Amplitudes.				Phase Angles (L.A.T.).			
	c_0	c_1	c_2	c_3	c_4	a_1	a_2	a_3	a_4	c_0	c_1	c_2	c_3	c_4	a_1	a_2	a_3	a_4
	mb.	mb.	mb.	mb.	mb.	°	°	°	°	a.	a.	a.	a.	a.	°	°	°	°
January -	1007.01	.094	.227	.130	.054	171.1	151.1	355	221	276.59	0.59	0.29	0.11	0.03	227.4	48.7	225	39
February -	1007.08	.156	.270	.104	.026	175.6	148.7	355	96	276.75	1.03	0.44	0.12	0.01	229.6	47.6	224	157
March -	1006.89	.164	.295	.052	.031	158.2	150.8	336	35	277.34	1.63	0.45	0.07	0.08	232.7	59.5	336	211
April - -	1009.03	.153	.284	.019	.044	154.6	150.6	188	359	279.13	1.87	0.31	0.15	0.06	236.9	94.3	30	272
May - -	1011.44	.098	.237	.059	.022	135.5	142.9	163	329	281.65	1.95	0.20	0.16	0.09	239.9	150.7	61	29
June - -	1011.97	.057	.219	.065	.008	104.0	141.3	155	331	284.54	1.99	0.25	0.14	0.11	242.1	180.6	85	48
July - -	1009.64	.089	.208	.068	.013	136.6	144.2	159	345	286.38	1.96	0.19	0.16	0.11	241.3	163.7	64	30
August -	1008.23	.112	.232	.041	0.29	161.9	145.1	167	336	286.18	2.02	0.26	0.19	0.06	238.3	108.1	49	346
September -	1010.00	.119	.287	.027	.053	146.1	147.8	342	339	284.34	2.01	0.46	0.14	0.10	234.2	74.9	13	228
October -	1007.31	.155	.274	.075	.027	183.1	149.1	349	20	281.42	1.42	0.53	0.09	0.07	230.6	53.8	252	195
November -	1006.64	.132	.229	.103	.014	197.5	152.2	354	172	278.68	0.83	0.38	0.15	0.02	228.0	50.1	222	25
December -	1004.26	.164	.211	.122	.051	169.3	146.4	356	204	276.86	0.46	0.23	0.12	0.04	230.1	50.1	226	44
Year -	1008.29	.116	.247	.030	.009	162.9	148.7	0	340	280.82	1.47	0.25	0.03	0.01	236.0	74.9	40	11

above mean sea level, 26.8 metres: thermometer, 12.5 metres above ground level. The pressure is expressed in millibars as at station level, and is corrected for temperature and gravity. Temperature is given in degrees on the absolute scale. Phase angles are given in terms of local apparent time.

While the table exhibits the usual features, one or two interesting points may be noted. With regard to the pressure constants, the results taken over 56 years show a regularity in the changes of c_1 which is not found in observations over short periods. Generally speaking, the values are lowest in summer. The phase angles α show a parallel change. The amplitudes of the 12-hour term c_2 exhibit the usual double oscillation in the year, and it is of some importance from a theoretical point of view to note that this is in fairly close correlation with the corresponding term in the temperature. The 8-hour term c_3 is known to reach a minimum, if not to disappear, at the equinoxes, and this is fairly well marked. Harmonic analysis by fortnights, if not by weeks, instead of months, would be required to bring this out in greater prominence. The corresponding reversal in phase, through 180°, in the value of α_3 is also present. The changes in value of c_4 are somewhat irregular, but the nearly constant value of the phase angle α_4 during the middle six months of the year is noticeable.

The constants in the series for temperature also show some points of interest. During the first three and last three months of the year, the values of c_1 are proportional to the length of the sunlit day. After March, the rate of increase of c_1 with length of day becomes smaller. After midsummer, the reverse process takes place, but the ratio of c_1 to length of day is higher than in the first half of the year. With regard to c_2, its similarity to the corresponding pressure constant has already been noted. But the phase angles in pressure and temperature behave differently. For pressure, α_2 shows a double oscillation: for temperature there is a clearly marked single oscillation during the year. The latter is quite obviously related to the length of the sunlit day. The regular manner in which the ratio c_1/c_2 changes throughout the year may also be noted. There are some indications that the amplitude c_3 for temperature tends to a minimum at the equinoxes in the same manner as the corresponding pressure term.

A. CRICHTON MITCHELL.

The Cold Spell of February, 1929

(The earlier part of this note is amplified from the informal five minutes' talk given at the meeting of February 20.)

The frost of February 1929 was the most severe since that of 1895. Like most prolonged cold spells in the British Isles, it was due to east winds from the Continent, associated with high pressure over northern Europe. The chart reproduced (Fig. 1) is that for 7 a.m. on February 11, when the really severe cold first reached the British Isles. It may be seen that a large anticyclone was centred over Finland, with a pressure of 1044 mb. (30.83in.) at the centre. From the distribution of the isobars over Europe it is evident that there was a continuous flow of air from Siberia. So far as one can judge, that particular anticyclone developed over northern Russia during February 8, forming an extension of the Siberian anticyclone. Between the 9th and the 12th it moved westward about 600 miles, becoming partly detached from the Siberian system,

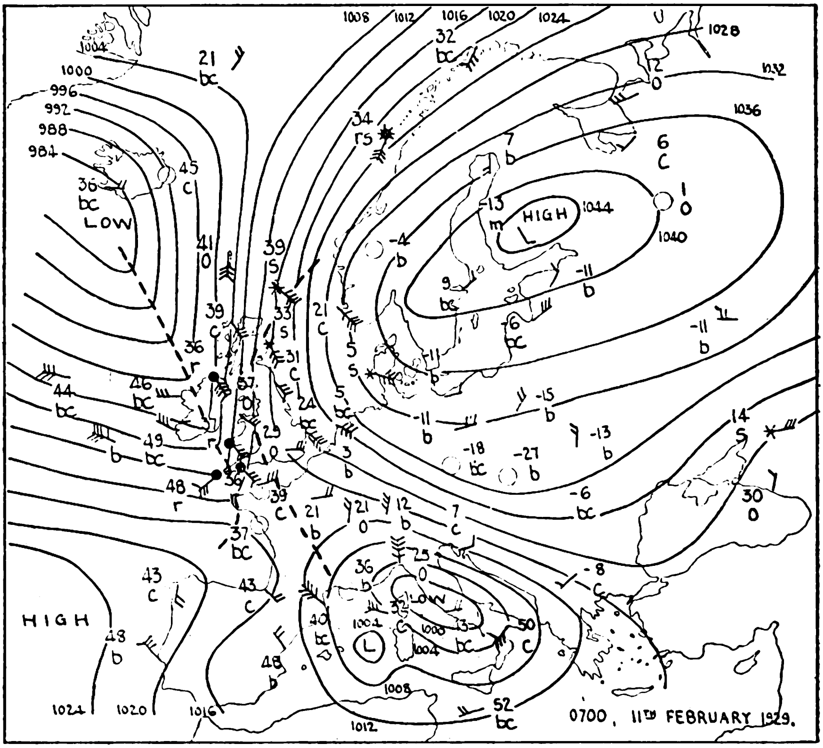

Fig. 1.

and this westward movement was the primary cause of the sudden extension of the very cold weather. The conditions were rather similar to those prevailing during the great frost of February 1895, which was longer and more severe than that of 1929. Dr. C. E. P. Brooks[1] has recently pointed out the resemblance of the mean pressure distributions in December and January 1928-9 with those in the corresponding months of 1894-5. This similarity has been maintained, but in both seasons the Icelandic anticyclone of January died out before the northern European anticyclone developed, so that the sequence was not due to the eastward movement of an anticyclone.

The two dotted lines on the chart mark the "fronts" between different air masses. The boundary of the very cold continental air is shown by the more easterly of the two fronts. Between the fronts there was a mass of returning polar air, while the westerly current consisted of a mild type of maritime polar air, the western front being of the nature of an "occlusion." Subsequently the two fronts became joined into one, and snowstorms with heavy drifting occurred over a large area in the west, notably in Devonshire, Wales, and the extreme south-west of Scotland. The snowstorm was associated with a secondary depression which formed on the "occlusion" and moved south-east to the Mediterranean. A similar development on February 15 caused further snowfalls in the south-west, the depth being large in parts of Devonshire. In most eastern districts the snowfall was trifling, unfortunately for agriculturists. Near the east coast there were some moderately heavy local falls, notably in east Kent on February 14. On that occasion the air had crossed a long stretch of the North Sea, owing to a complex modification of the pressure distribution. Such local snowfalls are usually due to moisture and warmth derived from the sea and seldom extend far inland. They develop readily when temperature is low in the upper air, and in consequence convection is active. In order that the temperature may remain below the freezing point over the sea surface, the upper air temperature must be very low indeed, as it was on this occasion.

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[1] *Meteor. Mag.*, **64**, pp. 1-4.

The cold spell was on the whole more remarkable for the coldness of the days than for the night frosts, though a screen minimum of -1°F. occurred on the morning of February 14 at Ross-on-Wye, where there was a good snow coating. At Manston, in Kent, temperature remained below the freezing point for a period of 226 hours. Large quantities of pack ice formed on the Essex coast. Day temperatures at ground level are closely related to the temperatures prevailing at the height of a few thousand feet. In the earlier part of the cold spell the upper air temperature was very low, but subsequently it rose considerably, and the maximum ground temperatures rose accordingly, though there was still a continental air supply with severe night frosts. Between February 14 and 20, temperature rose about 30°F. from a height of 3,000 feet upwards.[2] During this period the anticyclone had extended considerably south-westwards, and barometric pressure over south-east England had risen about 25 mb. Similar effects have often been observed before, and there can be little doubt that the dynamical warming of slowly descending air played an important part in producing the rise of upper air temperature, a hypothesis supported by the dryness of the air. This " subsidence " effect can, however, hardly account for the whole of the rise of 30°F.

About February 21 the Scandinavian anticyclone, which had withstood the assaults of many Atlantic depressions, suddenly collapsed for no obvious reason, and there was a short interval of milder weather. On the 23rd, however, a new anticyclone quickly developed over Scandinavia, and the cold E. winds returned on the 25th, bringing more very cold days, due on this occasion to a heavy sheet of cloud rather than to the depth of the cold air. Strong winds and damp air added to the feeling of coldness. Further snowfalls occurred in many districts, and it was reported by the Rev. H. H. Breton that a glazed frost occurred in South Devon during the night of February 26.[3] During this period temperature was high in France, and the glazed frost was due to rain falling through a shallow cold layer near the " front."

On February 28 the anticyclone moved quickly down from Scandinavia to the British Isles, and persisted. There was another period of prolonged subsidence, with a progressive rise of day temperature. In a week the days were abnormally warm for the season, Farnborough (Hants) having a maximum of 68°F. on March 9, with a diurnal range of no less than 43°F. in the screen. The relative humidity was 25 per cent at 1 p.m. Some other districts had equally low humidities and about as high maximum temperatures. The Farnborough maximum had risen 39°F. in ten days, possibly a record for these islands. The combination of summer temperatures and a wintry aspect of the country was very remarkable. There was still ice on lakes, and it was reported in the Press that there was actually skating on Derwentwater with a temperature little below 70°F. In most districts skating terminated by about March 6. Ground frosts were almost continuous from February 3 till March 12, though at most places there was a break on the night of February 23-24. It was only on March 20 that the period of ground frosts was generally terminated.

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[2] For details, see Fig. 2 of J. Crichton's article, *Meteor. Mag.*, **64**, pp. 30-34.
[3] *Meteor. Mag.*, **64**, p. 44.

In central and eastern Europe the winter was much colder than in the British Isles or France, not only absolutely but relatively to the normal. In some districts the temperatures were the lowest ever recorded. A figure of −15°F. at Berlin was the lowest in the records extending back for over a century. At Ivanov-Voznesenck, north-east of Moscow, a figure of −67°F. was observed. Waterways were frozen up over most of Europe, and three Simplon expresses were snowed up for over a week in Thrace. Spain escaped the cold almost entirely, and in Spitzbergen and the extreme north of Norway there was abnormal mildness. At Greenwich the period December to February has been colder on five occasions since 1841, and this may be taken as typical of eastern districts. Ireland was little affected, the mean February temperature in west Ireland being slightly above normal. In December and January the cold spells in Great Britain were not very intense, but a good deal of snow fell on high ground, and lay for considerable periods. On the higher parts of Devonshire the winter was especially severe, and the contrast between these regions and Cornwall illustrates what big differences may occur in a small area in the British Isles.

C. K. M. DOUGLAS.

Remarkable Changes in Wind Direction.

On more than one occasion during the summer of 1928 very well marked V-shaped traces appeared unaccountably on the wind direction records at Leafield, Oxfordshire. The charts were obtained with a Baxendell recorder, which gives a very open direction scale. The vane is 40 feet above the ground. The record for July 10-11 is so unusual that it seemed worth while to examine the conditions. Fig. 1 shows that soon after midnight the wind, after coming for some time from the SW more or less steadily, suddenly began to change in direction. It continued to change steadily for about a quarter of an hour until a maximum deflection was reached, then returned equally steadily to its original direction. A correction of +8° should be applied to the chart readings.

Records obtained with a Dines pressure-tube anemometer, working with the Baxendell recorder, show that the velocity decreased from about 5.5 m/s. to 2.1 m/s. as the direction changed, and increased again as the direction returned to normal. The Robinson-Elliott recording anemometer at the top of a 300-foot wireless mast showed a more sharply defined lull, the wind velocity dropping from an average of 11 m/s. to 6 m/s. and then rising again to its former value (Fig. 2). The temperature at 4 feet fell 2°F. as the wind backed, and rose 2°F. as it veered again (Fig. 3). Records of temperature gradient are obtained at Leafield by platinum resistance thermometers placed at intervals up the wireless mast; these records show that on the previous

day there had been a big mean lapse rate of over 4°F. in the first 300 feet; by 19.00 h. a slight inversion had been established in the first 40 feet, but it did not reach up to 300 feet at any time during the night.

The effect is clearly not due to any kind of rotary motion of the air about a vertical axis. Nor does it have any relation to the squalliness observed in the direction and velocity traces of polar air, for we were in a region of light or moderate SW winds on the fringe of an anticyclone over France. No discontinuities or kinks in the isobars could be discovered on large-scale weather maps to explain the changes in wind.

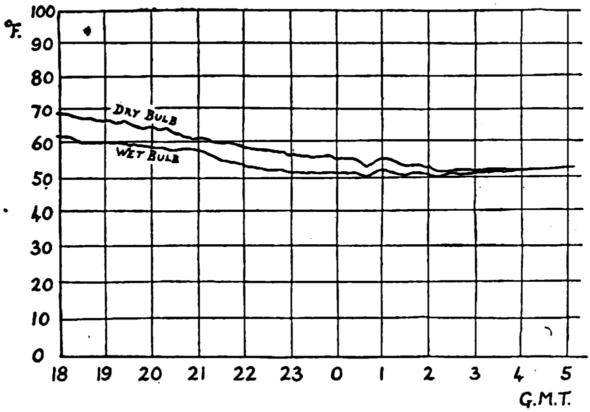

FIG. 3.—Temperature.

The phenomenon happened on a clear night; this suggests some sort of katabatic effect. The Research Station stands on the top of a broad ridge which divides the Evenlode and Windrush valleys (see Fig. 4, in which an outline map of the district is combined with a vector diagram). The watershed extends west by south and north-east by east of the station; the ground falls most rapidly to the north (300 feet in 1½ miles), and to the south-east (250 feet in 2 miles). Owing to our position on the top of the ridge we do not observe the ordinary katabatic effect of cold air creeping down the hillsides. When this effect is going on there must be a supply of air to the hilltops to take the place of the air which has flowed downwards; this brings us to a possible explanation of the mysterious changes in wind direction. On a night when an inversion extends up to a considerable height, one would expect the supply to take place by a gradual subsidence of the air over the high ground, producing no sudden changes in the wind. This was not the case, however, on the night of July 10-11, for there was only a slight ground inversion. During anticyclonic weather sudden temporary falls of temperature of several degrees have sometimes been observed; these must show the arrival of well-defined isolated volumes of cold air, possibly caused by unequal heating during the day. The big lapse rate on the previous day would favour the formation of inequalities in the air temperature, and since the evening inversion never extended to any great height, it seems reasonable to suppose that some such mass of cold air persisted into the night, and caused the drop in temperature which accompanied the change of wind. The arrival of a mass of cold air on the high ground would act as a source for the katabatic flow of air down the slopes on each side of the ridge, and air being sucked from the base of the mass would cause changes in the wind direction.

Fig. 4 is a vector diagram of the wind on the night of July 10-11. OA is a vector representing the mean wind for half an hour before and half an hour after the occurrence; OB, OC, OD, etc., represent the wind at 5-minute intervals during the change. Thus the extreme direction to which the wind backed is given by OE. If the centre of the mass of cold air passed slightly to the south-east of the station, we should have come under the influence of the stream of cold air escaping from its base straight towards the nearest point of the Evenlode valley to the north. This would explain why the wind backed towards the SE until this transverse stream of air had reached its maximum velocity, and then veered again to its original direction.

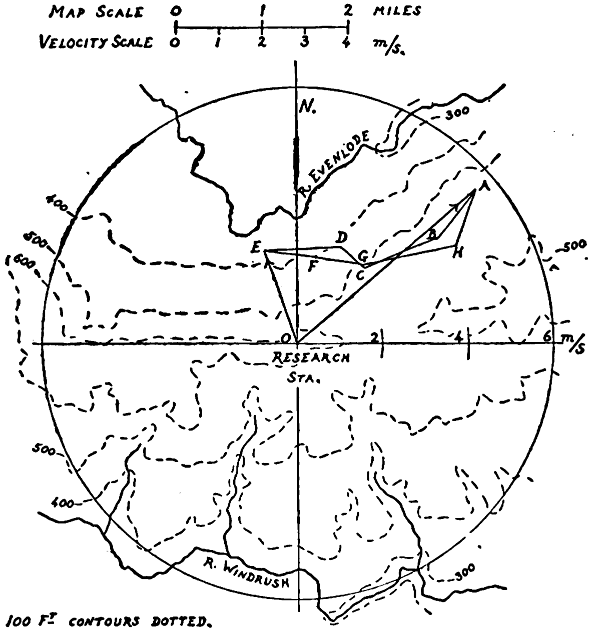

FIG. 4.—Vector diagram of wind.

In support of this suggestion, the temperature-gradient records show a temporary increase in the inversion near the ground. The very pronounced lull in the wind at 300 feet shows, however, that the changes in wind direction at 40 feet were not merely ground effects. The arrival of sluggish cold air might be expected to cause a lull, but it is difficult to see why the lull was more sharply defined at 300 feet than at 40 feet.

" V's " of the same type appeared on the charts of wind direction for July 12 and August 28, under very similar conditions. On these occasions the wind first veered instead of backing, but when the maximum deflection was reached the air was again tending to flow away from the line of the watershed towards the low ground, this time to the south. In spite of what has been said above, it is very hard to picture the state of the air which can produce such extraordinarily sharp changes on the wind charts, especially during settled weather.

G. S. P. Heywood.

Wind at a Moderate Height in a Suburban Garden

Meteorologists are well acquainted with the importance of an open exposure for anemometers if the records are to be reasonably representative of the general wind current. In consequence of this the official records of wind, on the whole, refer to open situations and do not provide any information about the motion of the air at a moderate height of 5 or 10 feet through the streets of towns or across an agricultural country with woods and fields and hedges, or in suburbs with houses and gardens.

An experience in November last (1928) led me to enquire whether any information existed for the last of these three situations, and, finding none, I obtained the loan of an anemometer (Robinson type with 3-inch cups and 7$\frac{3}{8}$-inch arms, recording according to factor 2.73), and set it up in my garden at a height of about 8 feet above the ground. It is about 10 yards to the west of the north-west corner of the house, which is oriented approximately north-north-west to south-south-east and stands on ground about 4 feet below that on which the anemometer is placed. From the anemometer the ground slopes upward slowly to the south-west; there are no houses in that direction nearer than 100 yards. To the north the nearest houses are about 60 yards away and to the east about 100 yards. To the south of the instrument there is a hedge about 7 feet high and about 7 yards away. There are isolated fruit trees and shrubs in the garden, the nearest to the anemometer being an apple tree about 10 yards to the west.

From the point of view in question, namely wind in suburban gardens, the situation can be regarded as a comparatively open one.

The anemometer began to record on the 1st December, 1928. As no information could be found which would indicate what sort of a record would be obtained, rough estimates were made beforehand of what the run for a complete winter month would be likely to be. The estimates of different persons varied from 3,000 to 6,000 miles. The actual run for the two months, December and January combined, was 3,400 miles (December, 1660, January 1740). During the same two months the total run at Kew Observatory on the Robinson cup anemometer (70 feet above ground) was about 9,400 miles (December 4,800, January 4,600), and the corresponding run deduced from the records of the pressure-tube anemometer at Croydon Aerodrome (150 feet above ground) was 15,500 miles (December 8,000, January 7,500). If we turn these into speeds the mean figures for the two months are:—

Hurst Close	2.3 m.p.h.
Kew	6.3 m.p.h.
Croydon	10.4 m.p.h.

(If the values were "reduced" to the standard height of 10 metres (33 feet) above ground they would be: Hurst Close 3.1, Kew 5.5, Croydon 8.7).

The greatest run for a single day at Hurst Close was from December 31 to January 1—160 miles, or approximately a mean wind of 7 m.p.h. The mean wind at Kew Observatory for December 31 was 16 m.p.h., the highest value in the two months, and at Croydon Aerodrome 17 m.p.h., but at Croydon there were two days of higher mean wind in the period, namely December 26 with a mean wind of 22 m.p.h., and January 29 with a mean wind of 23 m.p.h.

From the daily records at Hurst Close I got the impression that December and January had been exceptionally quiet for winter months. I find that the value of the mean speed at Kew is nearly 2 m.p.h., or about 25 per cent below the normal, but that is a much smaller difference than I had anticipated.

The records are being continued, but the values to date seem to me to be interesting. Possibly other Fellows may be able to obtain similar records which would give some idea of the variation to be expected in the wind at 8 feet above the ground in gardens or small open spaces in towns or suburbs. Wind is a most important factor in evaporation, and it plays a part in plant growth: the effective wind from these aspects is the wind in our gardens and fields and not the wind of the ideal exposure.

E. Gold.

Meteorological Observations at the Radcliffe Observatory, Oxford, 1928. (Communicated by the Radcliffe Observer).

The following were the chief characteristics of the weather at Oxford during the year 1928:—

The mean *barometric pressure* at 9h. Greenwich Civil Time (barometer reading reduced to 32°F. and mean gravity) was 29.723 inches, which is 0.031 inch below the mean for 70 years.

The mean *maximum temperature* of the air was 58.0°F., which is 1.6° above the mean for 75 years. The mean *minimum temperature* of the air was 42.7°, which is 0.2° above the mean for 75 years. The absolute maximum temperature, 87.2°, was recorded on July 15; and the absolute minimum, 20.4°, on December 15. The lowest grass minimum temperature, 17.9°, occurred on December 15.

The temperature of the air reached 80° on 9 days and fell as low as 32° on 35 days. The number of days of *ground frost* (grass minimum as low as 30.4°) was 89.

The differences of the mean monthly temperatures (mean adjusted from maximum and minimum) from the corresponding means for 97 years are:—

	°F.		°F.		°F.
January	+3.1	May	−0.8	September ...	−0.5
February ...	+3.0	June	−1.9	October	+1.3
March	+2.1	July	+2.1	November ...	+3.1
April	+0.6	August	−0.4	December ...	−1.9

Wind. The total movement of the air recorded by the Robinson anemograph with cups 116 feet above the ground was 82,248 miles, the records being reduced with the factor 2.2. The mean monthly velocities of the wind are given in the following table:—

	mi./hr.		mi./hr.		mi./hr.
January	12.88	May	7.07	September ...	6.41
February ...	11.89	June	10.26	October	9.60
March	8.23	July	8.33	November ...	12.52
April	8.90	August	8.50	December ...	7.95

The number of hours of *bright sunshine* amounted to 1618, which is 137 hours above the mean for 45 years.

The monthly differences from the mean are shown in the following table:—

	Hours		Hours		Hours
January ...	... +19	May ...	... −27	September ...	... +64
February	... +24	June ...	... +26	October ...	... +22
March ...	... −19	July ...	... +56	November ...	... + 6
April ...	... −22	August ...	... − 9	December ...	... − 3

Rainfall amounted to 22.649 inches, being 3.544 inches below the mean for 111 years. The number of rain-days (0.005 inch or more) was 180.

The monthly differences from the mean were:—

	Inches		Inches		Inches
January	... +1.853	May ...	... −1.410	September	... −1.850
February	... +0.098	June ...	... −0.459	October ...	... +0.444
March ...	... +0.057	July ...	... −0.680	November	... +0.510
April ...	... −0.931	August	... −1.174	December	... −0.002

Solar halos were observed on 175 days, parhelia being present on 35 days. The 46° halo was seen on February 12, May 27, October 19 (with parhelic circle), and December 27. Contact arches were observed on 13 days. Sun pillars were seen on February 24 and 25, April 5, May 4 and 28, November 18, and December 25.

Lunar halos were observed on 51 nights, being accompanied by the 46° halo on January 2 and November 28, and a lunar bar on July 26.

The *zodiacal light* was noted on 16 evenings.

OBITUARY

Mr. C. S. Bilham

We regret to announce the death on January 23, 1929, at Southend-on-Sea, of Charles Selth Bilham, in his 72nd year. Mr. Bilham was Secretary and Manager of the Southend Waterworks Company.

He was elected a Fellow of this Society in 1907.

Colonel C. K. Brooke

The death occurred on January 7, 1929, at Ste. Maxime, France, of Colonel C. K. Brooke, in his 87th year.

Colonel Brooke joined the army as an ensign in 1862, and he retired in 1884 with the rank of major. During this period, as well as service at home, he served overseas in New Brunswick, Bermuda and Hong Kong. In 1888 he joined the 3rd Battalion of the East Yorkshire Militia, and he subsequently commanded the regiment for five years with the honorary rank of colonel. During the South African War he commanded the Royal Irish Reserve at the Curragh.

Colonel Brooke was the author of a book on field training; he also contributed several articles to the Journal of the Royal United Services Institution.

He was a Fellow of the Royal Geographical Society.

He was a Life Fellow of this Society, and was elected in 1879.

Sir John Wrench Towse.

We regret to announce the death on February 23, 1929, at Bickley, Kent, of Sir John Wrench Towse, at the age of 80.

John Wrench Towse was the son of William Beckwith Towse, of the Fishmongers' Hall, E.C., and he succeeded his father as Clerk to the Fishmongers' Company in 1889. As William Beckwith Towse had also succeeded his father as Clerk, the connection of the family with the

Company was a long one. Sir John Towse was always an eager worker in the many activities which concerned the Court of the Fishmongers' Company, and to him the formation and early success of several organisations were due. On retiring from his office as Clerk in 1921 the Court did him the honour to elect him a member of their body. He was knighted in 1911.

He was elected a Fellow of this Society in 1908 and he served on the Council from 1911 to 1913.

ANDREW WATT, M.A., F.R.S.E.

Andrew Watt, Assistant Superintendent at the Meteorological Office, Edinburgh, died suddenly on the evening of January 9, 1929, after he had attended to his usual daily duties. Born in Edinburgh in 1869, he was educated at Dumfries Academy and afterwards at Edinburgh Unversity, where he distinguished himself in the senior class of mathematics. After graduating his health broke down and he went out to Australia to recuperate. While there he joined the teaching profession and taught mathematics in the Scots College, Melbourne, until 1894, when he returned to this country. Thereafter he was a teacher in Nairn until he joined the staff of the Scottish Meteorological Society in 1900, as assistant to the late Dr. Buchan, and spent part of his time at the Ben Nevis Observatory. Shortly after the death of Miss Jessie Buchan in 1905, he became Assistant Meteorological Secretary to the Society, and on Dr. Buchan's death in 1907 he was appointed his successor. In the same year he was elected a Fellow of the Royal Society of Edinburgh. He was also Consulting Meteorologist to the Royal Scottish Arboricultural Society and for some time a lecturer on meteorology in the East of Scotland College of Agriculture.

For some time prior to that the general work of the Society had largely devolved on him and he gave it devoted service until its amalgamation with the Royal Meteorological Society in 1920. He edited the Society's *Journal* which, until its discontinuance, maintained a high standard, and not a few of the articles which it contained were from his pen. Questions of rainfall and climate particularly interested him. His devotion to the interests of the Scottish Meteorological Society was whole-hearted, and to the members of the Society and to observers throughout Scotland who consulted him he was always helpful and genial. Lectures on meteorological subjects, which from time to time he delivered at meetings of the Society, were always listened to with appreciation.

In 1919 it became evident that under post-war conditions it was impossible for the Society to continue on its old basis. Much of the meteorological work done by the Society was taken over by the Meteorological Office and the Society was amalgamated with the Royal Meteorological Society. Mr. Watt loyally assisted in carrying through these changes though they meant for him a change from the comparative freedom of shaping his own work, but in the new conditions he continued to give cheerfully of his best.

His wife died in August, 1927, after a lengthy illness, and after her death Mr. Watt seemed never to recover his old vitality. He was approaching the age limit of the Meteorological Office and his friends hoped that he would enjoy the leisure of retirement to which his loyal services entitled him, but the end came suddenly while he was in the midst of his work.

E. M. WEDDERBURN.

REVIEWS

Wetterkunde. By Prof. Dr. W. GROSSE. Berlin (Georg Stilke), 1928. 8°. Pp. 299. 13 M.

The author of this book was for many years director of the official weather service at Bremen, in north-west Germany. The book is intended for the layman rather than for the specialist and the treatment is entirely non-mathematical. Among its merits are its historical background and a certain breadth of treatment which brings out the relations of meteorology with other branches of physics, including their most recent developments. The general reader might be given an exaggerated idea of the importance of cosmic causes as compared with the complex workings of the atmospheric engine itself and with geographical factors. No one would quarrel with the attention given in the first chapter to solar radiation, but the passages quoting some very speculative conclusions on the influence of cosmic rays and cosmic dust might have been reduced. One misses any adequate discussion of the physics of the atmosphere. No doubt this is largely due to the restrictions which the author has imposed on himself, but the reader might have been helped to a better understanding of the weather as controlled by a three dimensional atmosphere.

A good deal of space is devoted to climatological data, especially of course to those of Bremen. The instructive series of diagrams illustrating the climate of Bremen form perhaps the most useful part of the book. There are altogether 107 diagrams and 5 plates, and more letterpress might with advantage have accompanied them, for the benefit of the cursory reader. C. K. M. D.

Der Wasserhaushalt des Coloradogebietes im Südwestlichen Nordamerika. By EBERHARD REICHEL. *Untersuchungen über die Denudation dieses Gebietes.* By MERCEDES LEITER. *Berlin, Geographische Abhandlungen,* 1928, 2 Reihe, Heft 4. Pp. 82.

The Colorado River has immeasurable potentialities. It is a probable source of hydro-electric power and affords possibilities for the reclamation of the desert land through which it flows. A study of the hydrology of the upper portion of the catchment area of this river, which drains to the Gulf of California, is therefore of considerable practical importance. In fact, it is only because of the many interests involved in the apportionment of the available water, no less than seven States being directly interested, that so detailed an investigation is possible. Further, the relationships given for the rainfall, run-off and evaporation are of particular interest because similar observations for dry regions are meagre.

The configuration, climatology and geology of this area of 627,000 square kilometres are dealt with initially. For some 23 stations details are given of the average annual and seasonal rainfall and seasonal temperature, and a map of the average annual rainfall is reproduced. There is an annual rainfall of less than 8in. over roughly one quarter and less than 16in. over three quarters of the total area. A relatively small area receives more than 40in. For some 40 catchment areas values are given for the rainfall, together with the corresponding values for the mean run-off. We have an area in the north with a rainfall of 24in., a run-off of 12.5in., and an evaporation of 11.5in., and in the south, areas near the main river, with a rainfall of 6in. and no run-off, and with a rainfall of 9in. and 1in. of run-off. There are six main types, the equations connecting rainfall n and run-off a varying from $a = (n - 10.6)\ 0.93$ in the case of the region to the north and $a = (n - 6)\ 0.05$ in the second district. Similar equations are given for the other types. In each case the equation is of course only applicable for limited values of n and a.

One of the most striking features of the paper is the reproduction of maps of both the run-off and the evaporation. There is a considerable area where the rainfall is insufficient to give any run-off at all, and in part of this region the evaporation is shown as less than 4in. In relatively wet areas the evaporation is more than 16in., while locally there is more than 24in. a year.

For certain districts annual values are given of rainfall and run-off and in each case it is shown, by means of dot diagrams, that the run-off increases fairly uniformly with the rainfall, in a manner comparable with that found for Great Britain and for Sweden.* There is a marked difference, however, in that while in Sweden the evaporation is fairly constant year by year, in the Colorado area it is appreciably less in dry years. In the south of Sweden, where the conditions are comparable with those in Scotland, in a wet year with a rainfall of 35in. the evaporation in a typical area was 11in., while in a dry year with a rainfall of 24in. the evaporation was 13in.; the evaporation is therefore somewhat greater in dry years. For the Colorado the evaporation in an area with an average general rainfall of 21in. varied from 11 to 13in., but there was no relationship to the annual rainfall. In a drier area the evaporation varied fairly uniformly from 11 to 7.5in. during the years with a rainfall varying from 15 to 9in.

The conclusions arrived at are not as definite as might have been anticipated. This is no doubt due to the many factors on which the run-off depends, such as the nature of the vegetation and the seasonal distribution of rainfall, neither of which is capable of very precise comparison. The difficulty of the subject is also reflected in the long list of no fewer than 182 references which is included in the paper.

The appendix deals with the denudation of this region. For a number of catchment areas the amount of solid matter carried down is given in tons per year and a map showing the mean amount of wearing-away in thousandths of a millimetre is given. Unlike the Nile, the mud of this region is mainly a nuisance and considerable sums are spent annually in disposing of the silt which enters the irrigation canals.

In these papers a large number of data has been collected and a thorough examination made of the hydrology of this region.

J. GLASSPOOLE.

Die Dauer der Schneedecke in Deutschland. Von ERICH HEBNER. (Forschungen zur Deutschen Landes-und Volkskunde, Bd. 26, Heft 2). Stuttgart (J. Engelhorns Nachf.), 1928. 8°. Pp. 103-166. Map and sketch map.

In this study Dr. Hebner gives quite an elaborate account of the average duration in Germany of "snow-cover"—perhaps the most significant aspect of the statistical study of snowfall. The "duration of snow-cover" is based upon the number of days on which snow lies according to the definition of the International Meteorological Codex of 1907, namely the number of days on which snow covers more than half the country around the place of observation at the hour of morning observation. The work is based on only 14 years of observations (1900-1914), and this perhaps is a weak point, but it is very unlikely that the general trend of the "isochions" across the map of Germany would be substantially altered in a longer period though their numerical values might be to some extent. The large accompanying map on which these lines of equal duration of snow-cover are drawn is graded in black and brown, and where here and there owing to the paucity of observing stations the course of the lines is doubtful they are dotted. The highest sea-level frequency, 100 days, occurs along the Polish and

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* See Wallén, Axel. Eau tombée, débit et évaporation dans la Suède méridionale. *Geog. Ann.*, Stockholm, **9**, 1927, pp. 181-208.

Lithuanian frontiers, the lowest, 20, along the Dutch frontier, though in Heligoland out in the North Sea the number is only 12. The mountains, however, in all parts of the country introduce high values, locally upwards of 150 days. The primary feature of the map is, therefore, the increase in the duration of the snow-cover eastwards and upwards due to decrease of the winter temperature. There is very little increase northwards for three fairly obvious reasons: first, in Germany as in most of Europe the mean winter isotherms run north and south; secondly, the greater elevation of southern than of northern Germany offsets the effect of latitude; and thirdly, except on the western side of the country, the range of Germany in latitude is not great. Closer inspection of the map soon shows the importance of precipitation which decreases eastwards, and tends to oppose the effect of temperature. This is of little consequence in the plains, but in the mountains once a certain degree of cold is attained, it has the effect of making the snow-cover in the warmer western mountains as lasting as in the drier eastern. It is pointed out that relatively to altitude, the mountain regions of Germany with the longest duration of snow-cover are the Harz in the extreme north, the Inn Valley in the Alps of the extreme south, and the Sudeten in the extreme east, the first and second on account of precipitation, and the third on account of low temperature. At Klaustal about 1,800 feet up in the Harz Mountains snow lies for 110 days in the year. This is a high figure, but it is interesting to note by way of comparison with our own country, that the highest figure given for Great Britain in the *"Book of Normals" at an altitude not exceeding 1,000 feet is 83 days at Braemar in the upper valley of the Aberdeenshire Dee. The figures for Klaustal and Braemar are of much the same order when allowance is made for difference of height, but it should be remembered that the Scottish station is a good deal farther north than the German station.

More local factors affecting the length of time that snow lies are position with respect to the windward and leeward side of mountain ranges, foehn valleys, cold-air mountain valleys, and the like. The duration increases with altitude more rapidly on the windward than on the leeward side of mountain ranges, except in the case of narrow ranges. In the Harz a broad plateau separates the two sides, and the increase with altitude on the eastern leeside is smaller. One wishes, however, it were explained more fully which winds bring the most snow in Germany. It must be remembered that Germany, cut as it is by the winter isotherm of 32°F., occupies a transitional position between the freezing winters of eastern Europe and the more open winters of western Europe; and it would appear that in the German mountains the most snow-rich winds are not the dry, polar NE. winds, but the prevailing, moister SW. winds.

There are also a number of purely local factors influencing snow-cover such as slope, soil, and cities. Dr. Hebner points out that the effect of large industrial or urban areas like Westphalia and Berlin is so great in diminishing the duration of snow-cover that he has regarded them as natural factors influencing the course of the isochional lines, whereas for smaller towns he has applied a correction. The principle, however, seems to us to be one that might tax severely the philosophical judgment of an investigator in knowing "where to draw the line" in the sense of distinguishing between a city powerful enough to react upon its own climate and one that is simply the passive recipient of all weathers reaching it. The effect of Berlin in turning a certain proportion of the snow which falls in the surrounding country into sleet, and of the sleet into rain, is said to be striking. The effect of London,

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* The Book of Normals of Meteorological Elements for the British Isles. Section IV., 1923, published by H.M. Stationery Office.

too, is patent enough, though we are not aware that it has been experimentally demonstrated as in the case of Berlin. London's snowfall is certainly not representative of that of its surroundings, but the matter is complicated by the steady rise of the ground towards the escarpments which bound the Thames Valley. Altitude is an especially critical factor in the climate of England where in the persistence of snow the least elevation tells.

L. C. W. B.

The Last Glaciation. With special reference to the ice retreat in north-eastern North America. By Ernst Antevs. American Geographical Society Research Series No. 17. Shaler Memorial Series. New York, 1928. 8°. Pp. vi + 292, pls. ix. $3.50.

Dr. Antevs is a specialist in the study of the last Ice Age, and in the first half of this book he has given us his reasoned conclusions on many of its fundamental problems. It is a cold world that he pictures, but one of remarkable interest to meteorologists. At about the same time glaciers and ice sheets began to form in many distant parts of the earth, in North America, Europe and on the mountains of Asia, on lofty equatorial summits, in South America, Australia and New Zealand; in the southern hemisphere and in Asia they remained of small area, but in Europe, and still more in North America, they grew to enormous areas. Much depends on this question of synchronism, for it is deeply involved in the problem of continental drift; it appears that the synchronism of the latest glaciations of north-eastern North America and north-western Europe approaches to certainty, and taken in conjunction with close parallelism between Europe and Asia "convincingly shows that the glacial and interglacial epochs were essentially synchronous in all the northern hemisphere." In the same way South America agrees with Australia, arguing that there was synchronism in the southern hemisphere also; the general evidence, especially the glaciation of equatorial mountains, makes it highly probable that glaciation occurred at nearly or exactly the same time in all glaciated regions, though Antevs admits the possibility that there may have been "a slight difference in time between the greatest development of the glaciers under high latitudes on opposite sides of the equator." Practically, and the subsequent chapters strengthen this conclusion, the Ice Age was a definite episode of earth history, with a beginning, though perhaps not yet an ending.

The immediate cause for the beginning of glaciation was low summer temperature. This both increased the proportion of the year's precipitation which fell as snow, and decreased the amount of melting. In a few regions it appears that there must also have been at first an actual increase in the winter precipitation, but as the ice sheets grew in size there developed over them systems of outflowing winds which profoundly modified the general circulation. On the borders of the ice sheets these cold winds spread tundra over wide areas, while the storm tracks were deflected nearer to the equator and brought "pluvial periods" to many desert regions. Even close to the equator there was a distinct lowering of temperature, which permitted Alpine species to cross the low plains and establish themselves on isolated hills and mountains, so that Himalayan species, for example, are found on the hills of southern India. This tropical cooling may have been caused indirectly by increased cloud and rainfall, of which there is ample evidence.

The ice accumulations themselves were nothing less than monstrosities. At its maximum the North American ice sheet may have covered nearly 4,500,000 square miles, that of Europe over a million and a quarter square miles. From a series of careful calculations Antevs finds that in North America the ice probably reached a maximum thickness of 18,000 feet, and an average of some 7,000 feet, while in Europe the maximum thickness was 11,000 feet and its average some 5,000 feet. These figures are colossal, but they are borne out in a remarkable way by the lowering of sea level, which also proves that the major ice sheets reached their maximum at nearly the same time. For on the above calculations the total volume of ice in the northern hemisphere was eight million cubic miles in excess of the present volume, which corresponds with a layer of water 272 feet deep over the whole ocean. The volume of ice in the southern hemisphere at the maximum of glaciation exceeded the present volume by an amount equivalent to another 33 feet, so that if the maximum glaciation occurred at the same time in all parts of the world, the sea level would have been lowered by about 300 feet. On the other hand drowned river valleys in stable parts of the world indicate that the sea was formerly at least 250 feet below its present level.

The first half of the book is for the general reader, and especially for the meteorologist. The second, or special part, is mainly for the specialist. It consists of a full account of Dr. Antev's researches into the fluvio-glacial clays of North America, and the conclusions to be derived directly from them. The descriptions of the sections occupy 72 pages, and the material gathered is set out on nine large folding plates. A discussion of these "varved" clays appeared in the *Quarterly Journal* for January, 1928, pp. 64-70; here it is sufficient to recall that they are composed of a series of annual layers, the varying thickness of which represent variations in the rate of melting of the last ice sheets, and presumably therefore of the summer temperature from year to year. It is one of the tenets of the Scandinavian "geochronologists" that these variations depend on the supply of heat received from the sun, and hence are more or less similar in all parts of the world, and that a dated standard "solar curve" having been constructed for Sweden, the dates of ice retreat in other parts of the world can be fixed absolutely. Dr. Antevs, who has had experience in Scandinavia as well as in North America, recognises that agreement of varves alone is not sufficient, and that "only such varve connexions are valid as are based on curves showing good and persistent agreement, based on measurements from regions that were climatically similar in late-glacial time, and that for good reasons can be assumed to have become ice-free at the same time." On this conservative basis he equates the slow uncovering of southern Ontario with the prolonged oscillations of the ice border in the Danish Islands, which ended about 14,000 years ago. This was followed by a period of rapid retreat in both Canada and Sweden, but at a later date the Scandinavian ice sheet seems to have broken up more rapidly than the American, and it is suggested that this may have been due to the breaking of the Gulf Stream into the Norwegian Sea.

The book closes with a very good bibliography, occupying no fewer than 38 pages, which fills a long-standing need. Thus it can be said that the volume is in every way a valuable contribution to one of the most interesting and difficult problems of meteorology as well as geology.

C. E. P. B.

Dates of Flowering for Native and Garden Plants at Stavanger 1897-1926. By ASCHE MOE. No. 3 of Mathematico-Natural Science Classes, Norske Videnskaps-Akademi, Oslo, 1928. Published by the Fridtjof Nansen Fund.

This quarto of fifty pages includes a single page of introduction (in English) followed by forty-six pages presenting in tabular form data for some 1,400 flowering plants out of 2,000 in Mr. Moe's original records, now deposited in the University Botanical Museum in Oslo. For each plant are given records of the day of the month it was observed each year, and the resulting average date. Presumably the latter are weighted for missing years, which amount in some dozen or twenty cases to all but four or five. The tables must embrace well over 20,000 records. With rare exceptions, shown by block type, the plants flowered in the author's own garden. Perhaps one-third are native to the district. Needless to say, such a series puts his work in the first rank of similar compilations; probably it is unique. Moreover, it opens up a new area, the nearest long series, covering ten years or more, coming from Copenhagen. Our own country can muster three; one by Gilbert White of Selborne; another by Rev. Leo Jenyns of Swaffham, a century later, begun in 1820; and the unique school record of Marlborough College, begun in 1865. Our own series does not vie with the above as to the number of plants observed, its object being so different.

Such a monumental work, apart from its local values for farm and garden, is of prime scientific value. For it greatly extends the means of studying the relative effects of diverse weather conditions from region to region and from plant to plant. Naturally, to illustrate this on the small scale of a brief notice, we take for comparison our own series of fourteen plant records. All these appear in the Stavanger list except blackthorn, garlic hedge mustard, greater bindweed and ivy, every month from February to August being represented.

Plant.	British Isles average, 1891-1925.	Stavanger average, 1897-1926.		Difference, Stavanger − B.I.
Hazel (*C. avellana*) (female) ...	13.II	23.III		+ 38 days
Coltsfoot (*T. farfara*)	5.III	10.IV		+ 36 ,,
Anemone (*A. nemorosa*) ...	1.IV	11.IV		+ 10 ,,
Horse-Chestnut (*Æ. hippocastanum*)	13.V	29.V	+ 16 dys.	av. + 17½ ,,
Hawthorn (*C. oxyacantha*) ...	19.V	7.VI	+ 19 ,,	
White Ox-eye (*C. leucanthemum*)	3.VI	16.VI	+ 13 ,,	av. + 11½ ,,
Dog Rose (*R. canina*)	12.VI	22.VI	+ 10 ,,	
Black Knapweed (*C. nigra*) ...	9.VII	1.VIII	+ 23 ,,	av. + 6 ,,
Harebell (*C. rotundifolia*) ...	11.VII	30.VI	− 11 ,,	
Devil's-bit Scabious (*S. succisa*)	6.VIII	3.VIII		− 3 ,,

Very striking are the contrasting effects of climate; the Stavanger plants are mostly later than the corresponding plants in the British Isles, but there is a constantly lessening difference (except for the anemone) from over a month during the winter rigour to actual earliness when the insolation of long summer days has had its full effect.*

J. EDMUND CLARK.

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* Since this review was written Asche Moe has inquired whether we could provide a series of records near the North Sea and fairly near the latitude of Stavanger, 59°N. Fortunately Osgodby Agricultural Station, near Selby, about 54°N. but divided from the coast by the Wolds, had sent us a fine series for 1928. Asche Moe has found 42 correspondences, giving the following series of relative earliness at Osgodby. The number of plants is given in brackets. February (4), 30 days; March (4), 29; April (8), 18; May (9), 9; June (10), 7; July (6), 10; August (tansy), 2 days later; October (ivy), 13 days early. The lessening difference here is even more pronounced. One wishes a British long-period north-east record was available.—J. E. C.

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REPORT ON THE PHENOLOGICAL OBSERVATIONS IN THE BRITISH ISLES FROM DECEMBER, 1927, TO NOVEMBER, 1928.

NO. 38, NEW SERIES.

By J. EDMUND CLARK, B.A., B.Sc., IVAN D. MARGARY, M.A., F.R.G.S., RICHARD MARSHALL, F.R.A.S., and C. J. P. CAVE, M.A.

[Read May 15, 1929.]

EXPLANATORY NOTE.

Year Dates and Symbols.—The figures in the tables and text give the number of days before or after midnight, December 31. Thus (for Leap Year)

-31— 1=Dec.
1—31=Jan.
32—60=Feb.
61— 91=Mar.
92—121=April
122—152=May
153—182=June
183—213=July
214—244=Aug.
245—274=Sept.
275—305=Oct.
306—335=Nov.

In non-Leap Years subtract one day from the number after February.

Symbols.—In all tables, except Table IX., figures in *italics* represent interpolated values. In Tables III. and XI. these are used for calculating the *Station* means, but such figures are not used in computing *District* means. In preparing the tables all dates supplied by the observers are tabulated and critically examined. The most erratic, with reference to the other observations and the average date in each District, are then rejected and excluded from the Station and District means. They are not shown in Tables III. and XI., but in Table IX. they appear in italics.

From exigencies of space we have to restrict the tables compared with the records contained in the preliminary tabulation. Only those stations are printed which, in Table III. include seven or more records; in Table IX. include three birds or three insects; and in Table XI. eight birds, except in sparse districts. The original tables and the actual observers' reports are stored for reference, together with an abstract of their notes arranged under ten or more different subjects.

District means based on two observations are shown thus ( ), and if on a single record thus [ ].

Except in Table I., where they have the usual significance, the signs + and − indicate that the event was later than, or earlier than, the average date.

EXCLUSION OF ABNORMAL RECORDS AND INTERPOLATIONS.—These important points were dealt with at length in our 1927 Report.

THE SUBDIVISION OF DISTRICTS, carried out in 1927 for A, F and H, proved so satisfactory that we have this year divided D like them, to agree with the sub-districts of the Meteorological Office. We thus get D (i) west of a line south from Buxton. D (ii) lies to the east and extends up to Bawtry. D (iii) includes Derbyshire and the West Riding.

The total number of stations is 467, and yet serious blanks remain. Apart from Somerset and Dorset in the south-west, from the Wash to Warwickshire and the Welsh backbone, these occur chiefly north of a line from the Clyde to Berwick and in the western half of Ireland. But a glance at the map (Fig. 3) will disclose other areas not yet sufficiently filled in. Comparison with 1927 shows one or two welcome changes, the response to special appeals, for instance, in and near Shropshire, and, above all, in the West Lowlands, where we have been particularly assisted by the educational authorities, especially in Dumfriesshire.

followed by a warm, wet January, warmer February; the successive cold snaps in the spring months and June, and the excessive rains of that month and October.

Temperature (*Table* IA).—Again one needs weekly, rather than monthly values to bring out the more abnormal phases. When considering the vagaries of appearances in our records such references are essential, particularly for cold snaps and warm spells in the earlier months.

The following were the more noteworthy features:—

December.—Cold severe after the 10th with heavy snowstorms at the end of the month. The monthly mean temperature was more than 4° below the average in C, D and F.

January.—A very wet month; warm all through, with the mean temperature as much as 5.9° above the average in D during the second week.

February.—Mild, with heavy gales round the 11th. The mean temperature 6.1° above the average during the third week in E.

March.—Mild as a whole, with a notable cold spell during the second and third weeks, when the mean temperature fell to 5.3° below the average in District I. Very mild at the end of the month, when mean temperature rose to 6.7° above the average in C and D.

April.—Changeable and showery. Very warm at beginning and end of month, but a bitterly cold spell between, with mean temperature in D 7.8° below the average.

May.—Commencing very warm, the conditions changed to cool weather on the 5th, and remained so until near the end.

June.—Cold all through, except in second week, and in south England in third and fourth weeks.

July.—First week cool, then mainly warm. Hot in C, D and E during second and third week, also part of the fourth week, when the mean temperature rose to 5.3° above the average in C.

August.—Cool till 4th. Thereafter mainly fair, with temperature about normal in all districts.

September.—Commencing warm and finishing cold, the temperature as a whole was below normal. Very sunny in all districts, and dry except in the north and in the west and north of Ireland.

October.—Mild and wet generally after the first week.

November.—Began cool, then became mild and very stormy. In the third week the mean temperature exceeded 8.0° above the average in C and E.

For the separate months the average of all districts was markedly cold in December and June; the reverse in January, February and November. For the seasons the summer only was cool (−0.6°), the autumn warmest (+1.1°). Taking the year for the separate countries, the value for England is +0.7° (E+1.0°); Scotland −0.2°; Ireland +0.4°; the combined British Isles being +0.4°.

Rainfall (*Table* IB) was notable for its extremes. Three wet months followed the dry December, the January total being destructively in excess, averaging 204 per cent. of the normal. The areas exceeding 200 per cent. formed a broad band from C through D and F to H and J. June was little better in the last three districts, and H in October was again over 200 per cent. Five dry months—December, April, May, July and September—averaging only 75 per cent., nearly neutralise these excessive falls for the whole year.

Sunshine (*Table* Ic) was in excess save in spring, with only 82 per cent. of normal. January, 121 per cent., and September, 123 per cent., stand out, and the whole year was exactly the average. The variation from district to district ranges only between 90 per cent. in J, 96 per cent. in K to 104 per cent. in E, also the Channel Islands. C was specially favoured in July and September, with 137 per cent. and 146 per cent. respectively, and K in December recorded 156 per cent. against the 60 per cent. in D, repeated again in March.

Accumulated Temperatures (*Table* Id).—The differences from the average number of day degrees above and below 42°F. respectively for the four seasons were: 0, −37; +14, −27; +5, +2; +19, −28. As fresh averages have been worked out on a slightly altered basis, these values may not be strictly comparable with previous years, but we understand that there is no material difference. The phenological year for the British Isles gave a divergence from average aggregate of 38° excess above 42°, and 90° less below. The district divergences range from +201°, −78° in A to −204°, −81° in J. The values under 42° are all less than usual, but the opposite divergences for over 42° are remarkable. H with −162°, J with −204° and K with −123° are set against A, +201°, C, +185°, and E, +162°, thus strongly contrasting favourable conditions in England south of the Humber with unfavourable in all Scotland and less so in north-east England. This contrast was greatest in the summer months, when Ireland also was like Scotland. December and May contributed mainly to the shortage, −47° and −48° for all districts, as opposed to July and November, +46° and +42°. Phenologically the effective months were obviously May and July. In May H, J and K were short by 112°, 109° and 85°. July gave values, A, 60°; C, 107°; D, 108°; E, 122° above.

Coastal Sea Surface Temperatures (*Table* Ie).—The interest of the tentative table for 1927 has made it worth while to repeat it on what we believe is a more satisfactory basis. With the kind help of Mr. A. Hampton Brown, Mr. R. Marshall has worked out values based nearly all through on lightship records, so as to be of uniform character, using these same records from 1919 to obtain a ten-year average for comparison. It is, however, hoped to obtain still greater accuracy in the future.

The change in method prevents close comparison with 1927. We can, however, point out that the annual mean temperature then was slightly higher on the east coast and ½° higher on the west. Instead of February the lowest mean on the east coast for 1928 came in January, 40.8° against 42.6° as average. But, on the west, February remains coldest, though March was practically the same. In the east August gave the highest value, 56.3, against an average of 57.7. The west coast maximum, 56.5°, fell in September, compared with an average of 55.6°. The south coast minimum was 46.8° in January and February, though the averages for the two months are 47.6° and 46.0°. The lowest readings, very naturally, were in December and January on the east coast at 58°N., that of December, 37.3°, comparing with an average of 40.5°. At the other extreme come those of the *Royal Sovereign*, 51°N. up the English Channel, 62.5° in August and September, and Hartland, at 50°N., 62.4° in August.

Sea temperatures down our east coasts give a lower mean value than that of the adjacent land, but the reverse is the case on the west and south coasts. In 1927 the land was the cooler on both the west and east coasts. Seas in November were again warmer than in May, by 1.4°, 2.8° and 1.8° respectively on the three coasts, so great is the lag in rise and fall of sea temperatures. Previous to May, on the west coast, December is warmest by 2° and by nearly 1° on the south coast. The heavy excesses of temperature in 1928, except in the summer months, off south-east Ireland and the mouth of the Bristol Channel, is another important phenological factor, not brought to light by our other returns.

ISOTHERMS AND ISOHELS (*Fig. 2, December* 1927 *to July* 1928) are based for 1928 on 92 stations, or 45 per cent. increase on former years.

**Isotherms.*—51° again appears, as for 1927, in the extreme south-west, and the position of 50° differs little. The same is true over Ireland for 49° and 48°. 49° is shifted slightly southwards over Wales and England, lying entirely to the south of Sussex and Kent, save for an enclave from Canterbury to Ramsgate and Margate. Leaving Ireland over Wicklow, 48° curves north of Wales; then back down mid-Wales to pass north-east from Brecknock to south Nottingham; then round Leicester and through Buckingham to the sea in southern Essex. Thus it forms a great bulge of warmth over much of the Midlands up from the Bristol Channel, which we have seen was exceptionally warm. (See Isakair −10°, Fig. 4). 47° lies much further south over Ireland than in 1927. Passing out from near Belfast it curves north of the Isle of Man to follow the cool downrush over the north-west Midlands before passing up into the North Riding, there to curve back and out to sea in Lincolnshire. A warm enclave lies over north-east Norfolk. 46°, in the east, bulges south from the mid-Durham coast into the West Riding and then strikes north-west, passing out along the north of Mull. Instead of curving round a 47° enclave south of the Forth, as last year, we have a large area under 45° in the Border Counties and Peebles. In 1927 isotherm 45° just touched land between the Forth and Tay and cut off the north coasts of Caithness and Sutherland. In 1928, entering at the Tay it bulges south to 56°N. in Stirling, then passes north-west over Skye. Besides a central enclave under 44° over the Grampians and Cairngorms isotherm 44° cuts off the extreme north-east of Aberdeen and of Caithness.

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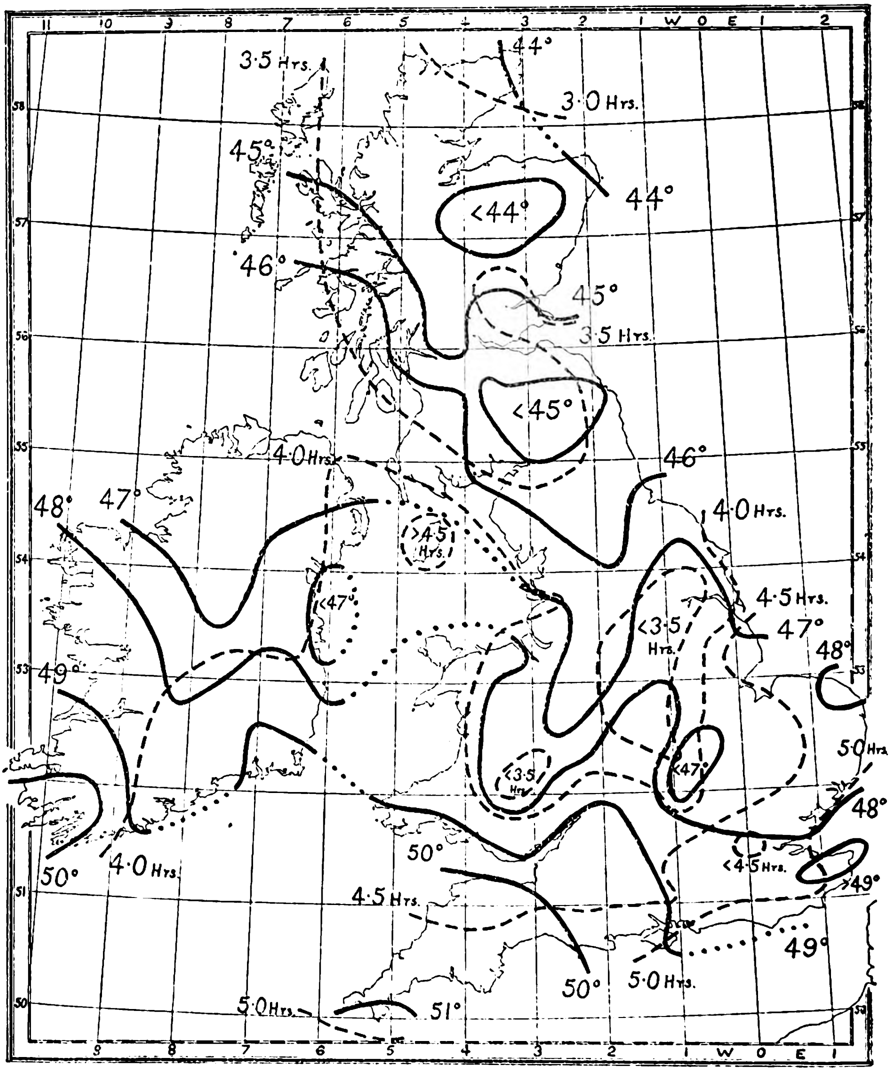
* Temperatures for these are reduced to sea level.

Thus the coolness of north and east Scotland during the chief phenological months is strongly emphasised. The range of mean temperature is from 51° at Penzance to 43.8° at Peterhead.

Isohels, again, confirm more brilliant weather in 1928. Coastal parts of Sussex, Kent and Essex are on the sunnier side of 5 hours against 4½ hours in 1927, the isohel for which is shifted northwards and westwards. The 4-hour isohel lies west of south-east Ireland and the coast line from Dublin to Antrim, crossing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50°
5·0 Hrs.
5·0 Hrs.
51°
9 8 7 6 5 4 3 2 1 W 0 E 1

FIG. 2.—Isotherms, or lines of equal temperature (°F.) (reduced to sea-level), and Isohels, or lines of equal sunshine (hours per day), during the eight months December 1927 to July 1928.

Isotherms ——— Isohels — — — —

over Wigtownshire to the Lune. Then, leaving the margin of west and south Wales on the sunnier side, it passes from here along the route of the 3½-hour isohel of 1927, to touch the coast near Scarborough. In south Britain the 3½-hour isohel includes only central parts from York and Hull to Birmingham and Warwick, with a bulge into Northampton fitting into a similar one of the 4-hour isohel extending into Buckinghamshire. A similar course occurred in the previous year with 3½ and 3-hour isohels. The latter isohel then replaced the 3½ hour, but with a south-west extension over Radnorshire. There, in 1928, we find an enclave of less than 3½ hours widely separated from the main area by the Severn Valley. Isohel 3½ hours does not appear over Ireland, but nearly all Scotland lies between it and isohel 3 hours, cutting off Caithness and north-east Sutherland.

Thus all districts were favoured in 1928 with more sunshine than in 1927. The extremes were 5.4 hours at Margate and less than 3 in Caithness.

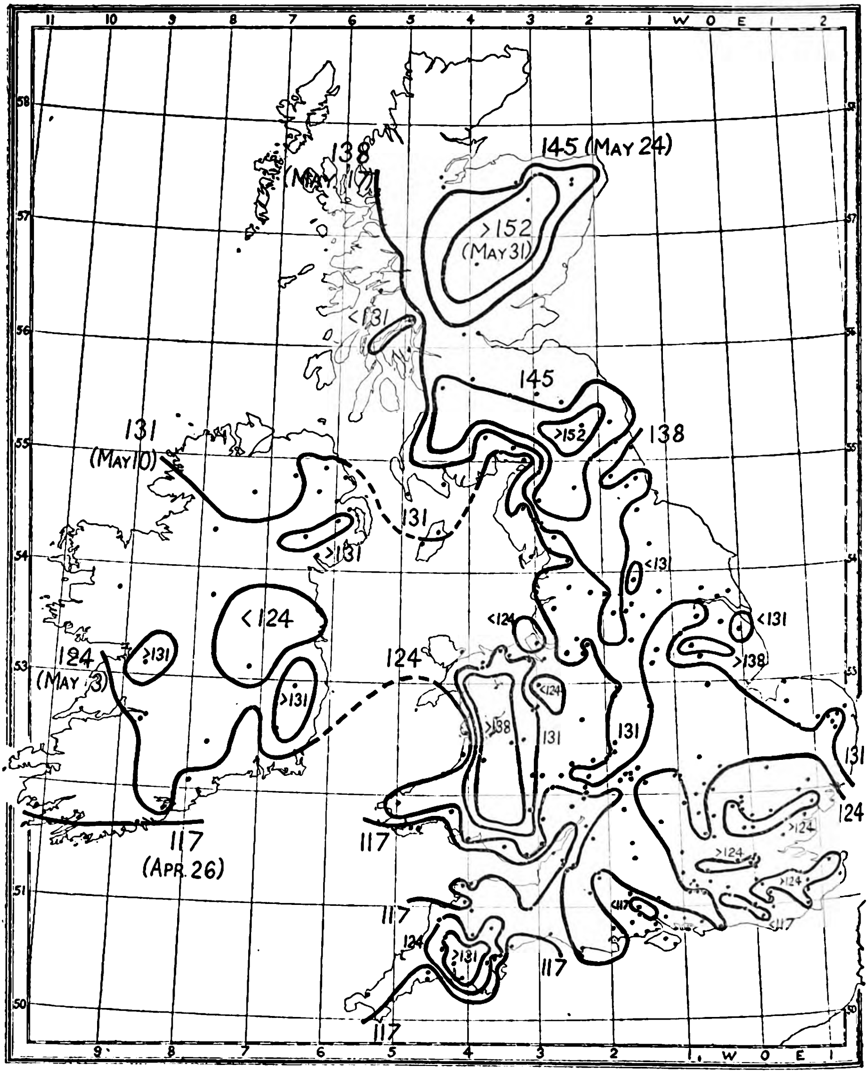
FLORAL ISOPHENES (Fig. 3; based on the 12 plants, hazel to bindweed).—The general appearance of the map is very similar to that of 1927, particularly in Ireland, the Scottish Highlands, the coastal regions of north-west England, and in Devon and Cornwall. Lateness was not so marked in central Wales, but was intensified in the Scottish Border district. As in 1927, the chief isophene is again 131, and its course is very similar, running from Lowestoft, near the Wash, to the Humber (but more inland over Lincolnshire this year), thence turning south-westwards, forming a narrow strip of lateness down to Worcester, thence northwards again to Manchester, and, skirting the Cumberland coast and Solway Firth, to Belfast and across to Donegal. Isophene 124 follows a more southerly course this year over southern England, touching the south coast at two points, whereas in 1927 there were only isolated areas of 124 so far south, and isophene 117 is practically confined to the south-western coasts instead of extending eastwards to Beachy Head. Both in the Lowlands and north-east Scotland the area of 145 is more extensive and in each case includes a considerable area later than 152 (May 31st).

FLORAL ISAKAIRS, or lines of equal divergence from normal dates (*i.e.*, of unseasonableness) (Fig. 4), form a convenient method of comparing the annual isophene map with the average map for the 35 years, 1891-1925 (Fig. 3a). The divergences from normal at any part of the map are thus readily seen.

The differences of the 1928 isophenes from those of 1927, noted above, tend towards a closer approximation to normal in most areas. Divergences of more than ±10 days are rare, occurring only in small enclaves in western Ireland, Dartmoor and north Norfolk (late) and in north Devon (early), while the neutral isakair 0 (no divergence) follows such a long and sinuous course that no part of the country is far from normal. Its meanderings exceed 2,750 miles, which is much greater than in any of the previous 37 years.

In very general terms, the main feature is an area of slight earliness stretching south-eastwards from Ulster to London but varying greatly in width, with a well-marked strip of lateness on its southern side, from west Ireland across Wales to Wilts, and with another, more broken, late strip on the north-east, appearing chiefly over the Highlands and Pennines, and down the east coast from the Tees to Lowestoft.

Floral Comparisons (Fig. 5 and Tables III. to VI).—The hazel, naturally, was of normal date, despite mildness in January,


11
10
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1 W O E 1 2
58
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54
53
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50
138 (May 17)
145 (May 24)
>152 (May 31)
<131
145
131 (May 10)
>152
138
131
>131
<131
<124
<124
124 (May 3)
>131
>131
124
<124
>138
131
131
<131
>138
131
124
117 (Apr. 26)
117
>124
>124
>124
117
124
>131
<117
<117
117
117
9
8
7
6
5
4
3
2
1 W O E 1

Fig. 8.—Weekly Floral Isophenes, or lines of equal flowering dates, from 117 to 152, for the 12 plants Hazel to Greater Bindweed, at about 270 stations.

117=April 26. 131=May 10. 145=May 24.
124=May 3. 138=May 17. 152=May 31.

1928 ——— Conjectural — — — —

(The effect of high ground is clearly evidenced, especially in the North.)
The dots indicate the stations used.

because of the deterrent effect of the severe December. In England and Wales the next six flowers, coltsfoot to hawthorn, were early. The untoward June brought the white ox-eye and dog rose back close to the average, followed by lateness with the remaining summer flowers. September once again brought the ivy close to average date. These sequences were less marked in Ireland and Scotland, so that in Table V the means of the spring flowers and of the autumn series differ by 5 days only, compared with 8 in south Britain. For individual plants Scotland E. gives the greatest divergence of 13 days late for knapweed and harebell. The exceptional and sole case of earliness, in Ireland N., is

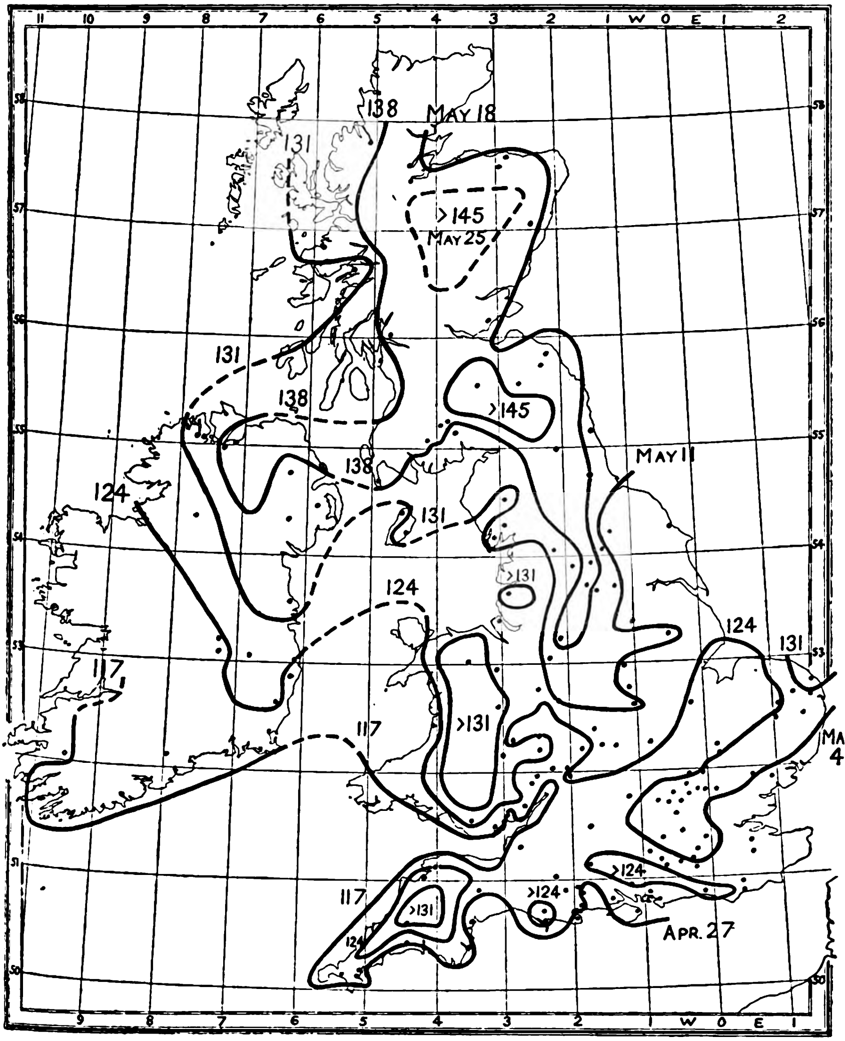
138
MAY 18
131
>145
MAY 25
131
138
138
124
131
>145
MAY 11
>131
124
124
131
117
117
>131
MAY 4
>124
>124
117
>131
124
APR. 27
11 10 9 8 7 6 5 4 3 2 1 W 0 E 1 2
58
57
56
55
54
53
51
50

FIG. 3A.—Average Floral Isophenes (35 years, 1891-1925).
(Owing to Leap Year one day must be subtracted from the monthly dates shown.)

notable. Our records are practically confined to the N.W., where the only outstanding features were warmth and excess of sun in May, followed by specially heavy rainfall in June.

For the 13 plants the range in south Britain is only from 1 early for the districts in England N.W. and S.E. to 2 late in N.E. For Scotland the range is −1 in W. to +5 in E. For Ireland −3 in N. to +2 in S. For Scotland E. only wood anemone (and scabious) was early; for Ireland N. only the horse-chestnut was late. Relatively to hawthorn the horse-chestnut lateness was general, culminating in Scotland N., where the dates were actually exchanged by the former being 11 days late and the latter 10 days early, each being based on 5 records. The difference for the British Isles was nil

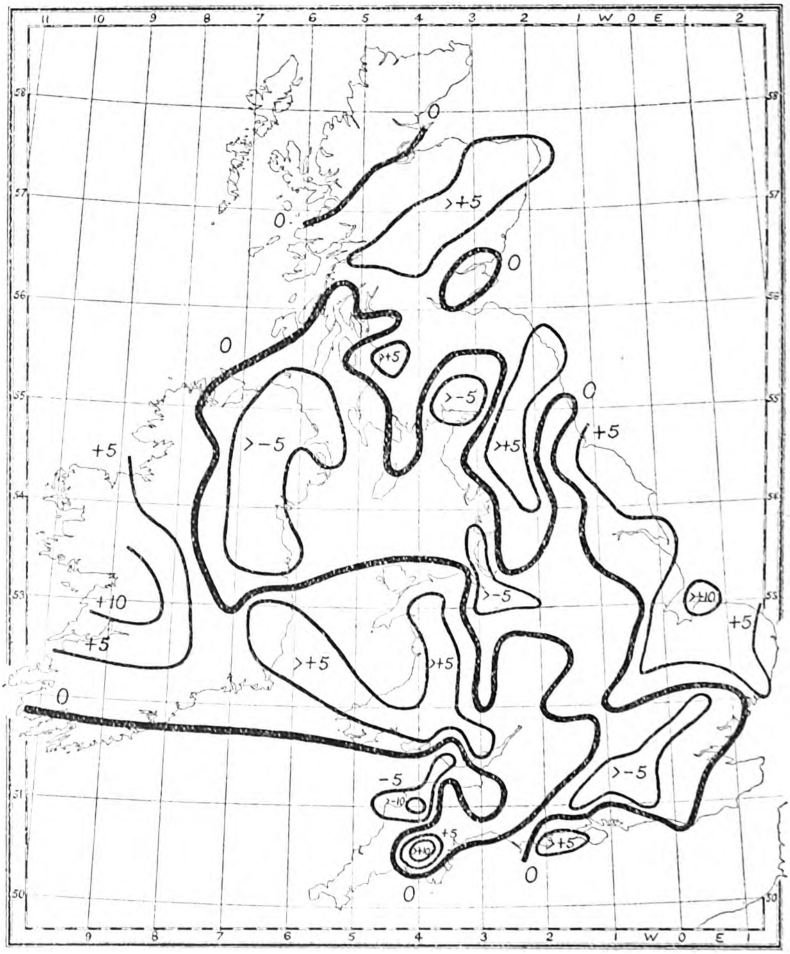

FIG. 4.—Floral Isakairs (*Gr. ise akairia* equal unseasonableness), or lines of equal divergence from the average flowering date for the 12 plants, hazel to bindweed, in 1928.

The lines indicate the distribution of differences of 5 and 10 days before (−) or after (+) the average date of the region for the period 1891-1925.

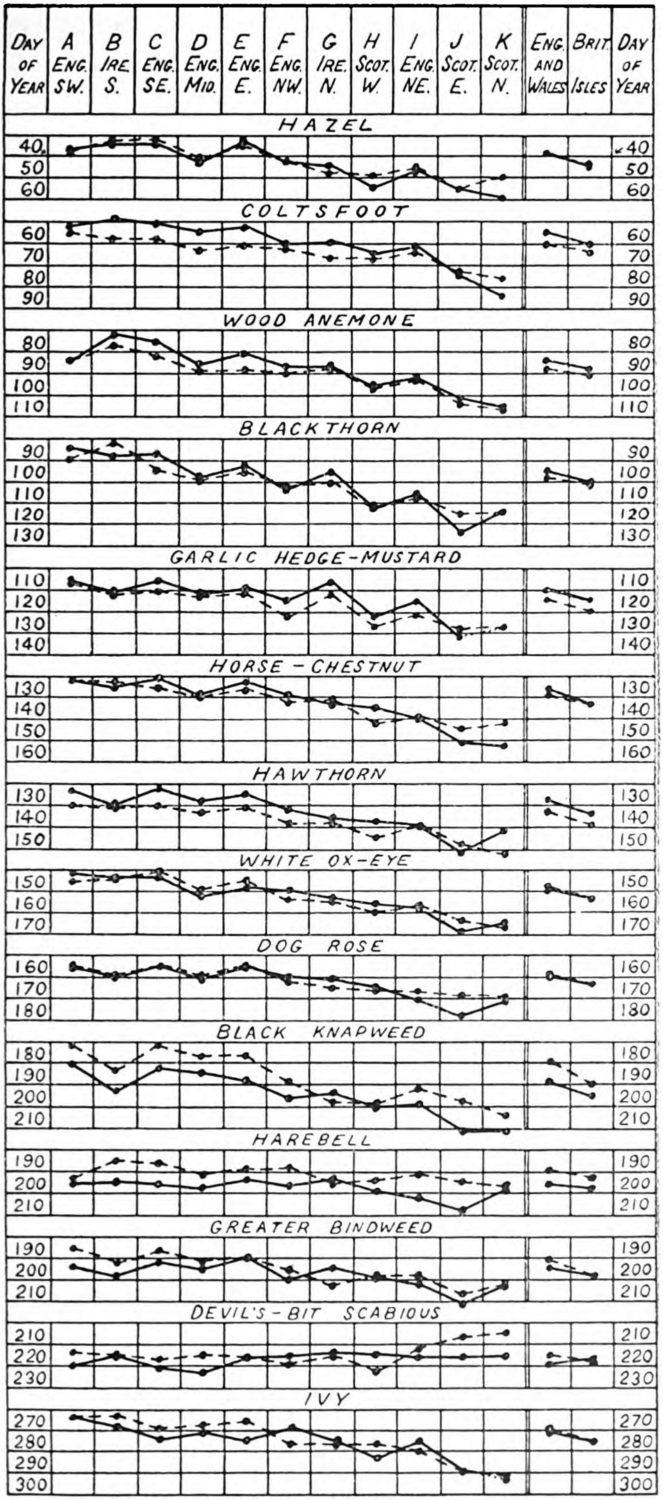

FIG. 5.—Dates of Flowering of Plants by Districts.

1928——— 35 years' average — — — Conjectural . . . . .

instead of six. The divergence from average between the early spring and late summer records for the three countries was: England 11 in S.E. to 5 in N.W.; Scotland 5 in E. to 0 in N.; Ireland 6 in S. to 1 in N. Thus the difference between greatest and least was practically the same in all three countries.

THE FOUR ADDITIONAL FLOWER RECORDS (Table IV), chosen to accentuate conditions early in the year, fully confirm what was said of the hazel. Their mean flowering date, February 5th, was 4 days later than the average. The additional very warm 8 days with 4° excess, helped to bring hazel up to time. No district was early. The 3 districts in southern England were practically on time; Scotland W. was 11 days late.

MR. LOWE'S RECORDS (Table VII).—Here again we find that the flowering of elm and hazel, the two earliest in average date, gave the only late records. But the tree and bush part company over leafing. The leaves of all but elm continued green longer than usual, especially the beech. The November gales resulted in most being prematurely bare.

OBSERVERS FOR THE INTERNATIONAL SUPPLEMENTARY LIST have increased materially. As this is now included in the main schedule we anticipate further increase for 1929 and on. The chief feature is the 10-days-late date of the Robinia ("Acacia") from the average in the schedule due to the abnormal June weather.

INSECTS (Tables IX and X).—The honey bee and orange tip, 4 and 5 days early, and wasp, 4 days late, indicate the usual rapid response of insects to special weather conditions, especially the first in Scotland, where 13 days before the average date, 67, coincides with the close of the abnormal February warmth. This continued longer in Scotland and Ireland than in southern Britain.

MIGRANTS (Fig. 6 and Tables IX. to XIII.).—That useful first songster, the thrush, again comes into play. It is three days early to be sure, but in 1926/7 it was 6 days earlier still, and was even 11 days early in District A, or January 4th; and January dates figured everywhere. December, 1927, precluded a repetition of such earliness; Scotland E. and N. have for date February 4th. With small exception the other arrival dates in Table X were early in all districts. For Table XI we have no district averages, but for the British Isles no bird was late. The lesser whitethroat arrived on the average date, 18 birds ranged from ½ to 3½ days early, with the last on the list of 20, spotted flycatcher, 4 days early. Taking the birds in the three sets the 5 earliest averaged 2½ days early, the middle 7 were 1½ days and the last 8 were 2 days early, giving for all a difference from our 15-year average of 2 days early. The North Midlands, D (iii), were 3½ days behind D (i) and D (ii).

THE RARER MIGRANTS (Table XII) have a much wider range, namely from 2½ days early (yellow wagtail) to 6 days late (ring ouzel). But the available records range from only 30 for the latter to 67 for the wood warbler; whereas in Table XI only 6 of the birds have less than 100 records (nightjar only 46) and 6 of them have over 200 records, headed by the swallow (432) and cuckoo (442).

Additional Bird Records (Table XIII).—The chief interest here lies in the result of splitting up Districts A, D and F. The spring records show that England S.W. preceded S. Wales by 5 days and N. Wales preceded England N.W. by 7 days, being in fact as early as England S.W. It was two days later in the previous year. Turning to the three Midland sub-districts, we have a still wider range, D (i) (west) preceding D (ii) and (iii) (east and north) by 4 and 12½ days respectively, the latter ranging little earlier than the Scotch districts. No doubt this is due to its lying so largely away from the coasts in the central elevated Pennine area. Also the excessive cold in D during mid-April must be borne in mind (−7.8°). The district values in spring range from 20.5 in England E to 41.7 in Scotland E. The autumn migration movements vary much less from district to district than

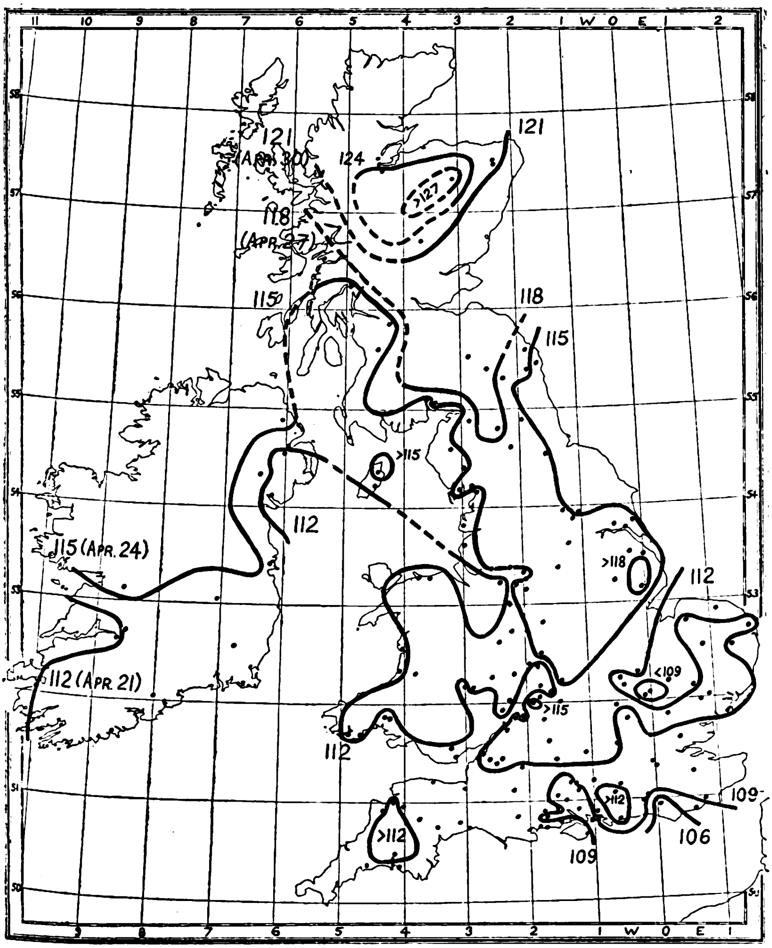
11 10 9 8 7 6 5 4 3 2 1 W 0 E 1 2
121 (Apr. 30)
124
>127
121
118 (Apr. 27)
115
118
115
>115
112
115 (Apr. 24)
>118
112
112 (Apr. 21)
<109
>115
112
109
>112
>112
106
109
9 8 7 6 5 4 3 2 1 W 0 E 1

Fig. 6.—Migrant Isophenes (lines of equal arrival dates), 1928, of the 20 birds enumerated in Table XI. The dots show the positions of the 173 recording stations.

TABLE I.—METEOROLOGICAL FACTORS, 1927/28.

+ indicates above the average, - below it.

A. *Mean Daily Temperature.*

MONTHS.	Mean Dis. 1-10.	Chan. Islands	A. Eng. SW. 8.	B. Ire. S. 10.	C. Eng. SE. 5	D. Eng. Mid. 4.	E. Eng. E. 3.	F. Eng. NW. 7.	G. Ire. N. 9.	H. Scot. W. 6.	I. Eng. NE. 2.	J. Scot. E. 1.	K. Scot. N. 0.
1927. December .	−3.5	−3.8	−3.8	−2.1	−4.0	−4.2	−3.2	−4.4	−1.9	−4.2	−3.6	−4.1	−3.0
1928. January .	+2.5	+2.8	+2.9	+2.2	+2.8	+3.4	+3.0	+2.7	+2.2	+2.1	+2.6	+1.5	+1.1
February .	+3.1	+3.3	+3.4	+3.3	+3.7	+3.4	+3.8	+3.1	+3.2	+2.6	+3.1	+1.7	+1.9
Winter .	+0.7	+0.8	+0.8	+1.1	+0.8	+0.9	+1.2	+0.5	+1.2	+0.2	+0.7	−0.3	0.0
March .	+1.1	+1.4	+1.5	+0.7	+2.1	+1.8	+1.9	+1.2	+0.6	+0.6	+0.4	+0.1	−1.2
April .	+0.6	+0.6	+1.3	−0.6	+0.6	+0.9	+0.5	+1.6	−0.2	+0.8	+0.4	+0.5	+0.9
May .	−0.1	−0.2	+0.9	+0.9	−0.4	−0.5	−1.0	+0.2	+0.8	+0.4	−1.1	−0.8	0.0
Spring .	+0.5	+0.6	+1.2	+0.3	+0.8	+0.7	+0.5	+1.0	+0.4	+0.6	−0.1	−0.1	+0.7
June .	−2.2	−0.8	−0.7	−1.8	−1.3	−1.9	−1.1	−2.7	−2.5	−4.1	−2.4	−3.3	−3.1
July .	+0.4	+0.6	+0.9	−0.2	+2.0	+1.3	+2.5	−1.1	−0.7	−1.9	+1.0	+0.2	−1.2
August .	+0.1	+0.5	+0.3	−0.5	+0.3	+0.3	+0.3	+0.2	−0.1	+0.2	+0.4	−0.1	−0.4
Summer .	−0.6	+0.1	+0.2	−0.8	+0.3	−0.1	+0.6	−1.2	−1.1	−1.9	−0.3	−1.1	−1.6
September .	−0.5	+0.8	−0.3	−0.6	−0.4	−0.3	+0.2	−0.6	−0.8	−1.4	−0.4	−0.9	−0.0
October .	+1.5	+1.6	+2.0	+1.9	+1.6	+1.9	+1.9	+1.3	+2.4	+0.9	+0.9	+0.1	+1.0
November .	+2.4	+1.9	+2.9	+1.9	+3.4	+2.9	+3.0	+2.1	+1.6	+2.1	+2.5	+1.9	+1.1
Autumn .	+1.1	+1.4	+1.5	+1.1	+1.5	+1.5	+1.7	+0.9	+1.1	+0.5	+1.0	+0.4	+0.4
Year (Dec.-Nov.) .	+0.4	+0.7	+0.9	+0.4	+0.9	+0.8	+1.0	+0.3	+0.4	−0.2	+0.3	−0.3	−0.1

B. *Total Rainfall per cent. of Normal.*

1927. December .	81	77	68	95	127	96	110	39	60	29	120	66	15
1928. January .	204	186	195	121	201	226	195	243	188	268	100	213	104
February .	115	147	123	113	90	119	86	155	143	136	82	107	151
Winter .	133	137	129	110	139	147	130	146	130	144	131	129	120
March .	124	135	140	176	112	124	93	93	107	128	127	139	86
April .	76	166	68	113	121	56	78	59	75	73	66	72	68
May .	75	199	65	82	108	52	119	67	55	61	73	73	77
Spring .	92	167	91	124	114	77	97	73	79	87	89	95	77
June .	173	120	137	212	117	125	128	204	193	206	100	223	161
July .	74	32	89	51	80	53	96	87	73	107	45	64	04
August .	112	88	90	134	84	85	90	114	140	131	120	134	04
Summer .	120	80	105	132	94	88	105	135	135	148	118	140	116
September .	70	84	60	75	45	33	46	62	119	109	36	111	90
October .	147	163	145	165	158	147	109	135	190	201	110	109	127
November .	128	108	125	132	119	129	103	157	135	148	110	126	120
Autumn .	115	118	110	124	107	103	86	118	148	153	85	115	117
Year (Dec.-Nov.)	115	126	109	123	114	104	105	118	123	133	106	120	108

TABLE I.—Meteorological Factors, 1927/28—*continued.*

C. *Daily Mean Sunshine per cent. of Normal.*

NTHS.	Mean Dis. 1 - 10.	Chan. Islands.	A. Eng. SW. 8.	B. Ire. S. 10.	C. Eng. SE. 5.	D. Eng. Mid. 4.	E. Eng. E. 3.	F. Eng. NW. 7.	G. Ire. N. 9.	H. Scot. W. 6.	I. Eng. NE. 2.	J. Scot. E. 1.	K. Scot. N. 0.
927. ember .	79	79	64	75	84	60	73	96	107	96	66	68	156
928.													
lary .	121	109	125	132	125	125	107	109	146	111	124	105	90
uary .	115	127	116	103	138	111	118	111	100	128	121	108	102
ter .	105	105	102	103	116	99	99	105	118	112	104	94	116
ch .	70	90	73	81	89	60	81	69	90	57	57	46	60
l .	89	90	89	90	87	82	79	93	103	97	89	76	86
.	88	94	86	103	87	71	84	91	106	101	77	76	77
ng .	82	91	83	91	88	71	81	84	100	85	74	66	74
.	100	101	88	91	111	103	110	92	105	98	105	97	103
.	114	125	115	105	137	131	133	108	92	83	137	99	73
ust .	102	99	98	119	107	104	100	98	110	96	104	82	85
mer .	105	108	100	105	118	113	114	99	102	92	115	93	87
tember.	123	137	123	113	146	124	139	118	112	122	112	122	117
ober .	104	123	112	99	109	119	117	103	81	89	108	99	108
ember.	101	77	85	91	103	104	106	90	95	115	118	101	94
umn .	109	112	107	101	119	116	121	104	96	109	113	107	106
r . c. Nov.	100	104	98	100	110	100	104	98	104	100	102	90	96

in 1926/7. Nor are the bird means very divergent from the average, save that the swift left 8 days later, the house martin 5½ days earlier, and the fieldfare came 4½ days earlier.

Migrant Isophenes (Fig. 6).—The map is noticeably earlier than that for 1927, by as much as six days in parts of southern and eastern England and central Wales. Isophene 115 runs northwards from Galway Bay to Argyllshire and then follows the west coast southwards, through Manchester to Warwick, where it turns sharply north-east to the coast of Lincolnshire and thence northwards parallel with the coast as far as the Border. In 1927 this isophene passed south of the Isle of Man, followed the coast of Wales and passed across southern England from Bath to the mouth of the Thames. Dates later than 112 only occur in southern England this year in two small enclaves, the main isophene 112 passing directly from south Wales eastwards to Colchester, well to the north of London, whereas in 1927 it hugged the south coast. Early arrival areas at Southampton Water, Lewes, the Wash, the Mersey, and very markedly up the Bristol Channel, are again clearly shown. Even the latest area in the Highlands only shows isophene 127, in place of 130 in 1927. There is still a very unfortunate shortage of migrant observers in central and south-east Scotland, as well as over much of Ireland.

(*Continued on page* 241.)

TABLE I.—METEOROLOGICAL FACTORS, 1927/28—*continued.*

D. *Accumulated Temperature* A *above and* B *below* 42° *F. (Day-Deg. F.), Variations from the Average.*

MONTHS (to nearest weeks).	Mean. A—J.		Channel Islands. 11.		A. Eng. SW. 8.		B. Ire. S. 10.		C. Eng. SE. 5.		D. Eng. Mid. 4.		E. Eng. E. 3.		F. Eng. NW. 7.		G. Ire. N. 9.		H. Scot. W. 6.		I. Eng. NE. 2.		J. Scot. E. 1.		K. Scot. N. 0.	
1927-28.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B	A.	B.	A.	B.	A.	B	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Nov. 27—Dec. 31	− 47	+ 70	−103	+ 21	− 62	− 59	+ 52	+ 22	− 63	+ 70	− 50	+ 89	− 48	+ 55	− 49	+103	− 31	+ 30	− 41	+101	− 40	+ 71	− 32	+104	− 22	+ 81
Jan. 1—Jan. 28 .	+ 25	− 52	+ 39	− 33	+ 37	− 46	+ 41	− 37	+ 31	− 54	+ 28	− 76	+ 21	− 72	+ 21	− 59	+ 35	− 37	+ 20	− 33	+ 16	− 57	− 3	− 50	− 5	− 49
Jan. 29—Feb. 25	+ 22	− 55	+ 46	− 29	+ 28	− 49	+ 30	− 48	+ 33	− 53	+ 24	− 66	+ 29	− 71	+ 21	− 59	+ 24	− 44	+ 14	− 49	+ 18	− 54	+ 4	− 59	+ 8	− 52
Winter . .	0	− 37	− 18	− 41	+ 3	− 36	+ 19	− 63	+ 1	− 37	+ 2	− 53	+ 2	− 88	− 7	− 15	+ 28	− 51	− 7	+ 19	− 6	− 40	− 31	− 5	− 19	− 20
Feb. 26—Mar. 31	+ 28	− 24	+ 56	− 8	+ 52	− 20	+ 44	− 25	+ 53	− 21	+ 41	− 29	+ 31	− 26	+ 31	− 22	+ 28	− 30	+ 11	− 37	+ 7	− 15	− 15	− 21	− 1	− 49
Apr. 1—Apr. 28 .	+ 14	− 5	+ 12	− 5	+ 23	− 2	+ 5	+ 3	+ 11	0	+ 17	− 3	+ 3	− 1	+ 37	− 10	+ 5	− 2	+ 17	− 18	+ 11	− 1	+ 5	− 8	+ 11	− 11
Apr. 29—May 26	− 28	+ 2	− 41	+ 1	− 13	+ 6	− 5	+ 3	− 50	+ 4	− 50	− 1	− 67	+ 5	− 20	0	+ 3	0	+ 7	+ 8	− 55	0	− 30	− 6	− 5	− 10
Spring . .	+ 14	− 27	+ 27	− 12	+ 62	− 16	+ 44	− 19	+ 14	− 17	+ 8	− 33	− 33	− 22	+ 48	− 32	+ 36	− 32	+ 35	− 47	− 37	− 16	− 40	− 35	+ 5	− 70
May 27—June 30	− 48	+ 2	− 19	0	− 7	0	− 35	+ 1	− 15	+ 1	− 33	0	− 23	+ 2	− 52	+ 2	− 46	+ 3	−112	+ 6	− 53	+ 3	−109	+ 3	− 85	+ 4
July 1—July 28 .	+ 46	0	+ 38	0	+ 60	0	+ 25	0	+107	0	+ 88	0	+122	0	+ 3	0	+ 4	0	− 43	0	+ 71	0	+ 25	0	− 14	0
July 29—Aug. 25	+ 7	0	+ 28	0	+ 14	0	− 18	0	+ 24	0	+ 12	0	+ 27	0	+ 7	0	− 3	+ 2	+ 2	+ 1	+ 11	0	+ 1	+ 1	− 2	+ 1
Summer . .	+ 5	+ 2	+ 47	0	+ 67	0	− 28	+ 1	+116	+ 1	+ 67	0	+126	+ 2	− 42	+ 2	− 45	+ 5	−153	+ 7	+ 29	+ 3	− 83	+ 4	−101	+ 5
Aug. 26—Sept. 29	− 7	+ 4	+ 23	0	− 1	+ 2	− 17	+ 4	0	+ 4	0	+ 3	+ 23	+ 3	− 8	− 1	− 20	+ 9	− 27	+ 9	− 2	+ 3	− 21	+ 5	− 13	+ 6
Sept. 30—Nov. 3	− 16	− 5	+ 12	0	+ 15	− 7	− 3	− 5	− 9	− 7	− 11	− 11	− 3	− 8	− 25	+ 3	+ 10	− 5	− 34	− 3	− 42	− 3	− 53	− 3	− 10	− 12
Nov. 4—Dec. 1 .	+ 42	− 27	+ 50	− 5	+ 55	− 21	+ 48	− 21	+ 63	− 24	+ 49	− 35	+ 47	− 26	+ 38	+ 2	+ 32	− 23	+ 24	− 39	+ 42	− 39	+ 24	− 47	+ 15	− 35
Autumn . .	+ 19	− 28	+ 85	− 5	+ 69	− 26	+ 28	− 22	+ 54	− 27	+ 38	− 43	+ 67	− 31	+ 5	+ 4	+ 22	− 19	− 37	− 33	− 2	− 3	− 50	− 45	− 8	− 41
Year . . .	+ 38	− 90	+141	− 58	+201	− 78	+ 63	−103	+185	− 80	+115	−129	+162	−139	+ 4	− 41	+ 41	− 97	−162	− 54	− 16	− 92	−204	− 81	−123	−126

E. *Sea Surface Temperatures from lightships along the Coasts of Great Britain, with approximate differences from the Average (Deg. F.), 1919 to 1928.*

Lat. N. of Station.	December.		January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		*Means. Dec. to July.	
	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Temp.	Diff.	Sea.	Land.
East Coast.																										
58° Kirkwall-Uzon	37.3	−3.2	39.3	−0.9	40.5	+0.2	41.4	−0.9	43.9	−0.8	47.3	−0.8	49.0	−1.8	52.7	−2.4	51.8	−3.6	51.1	−2.8	46.8	−2.8	43.7	−1.7	43.9	44.0
56° East Fern .	45.8	−0.2	42.5	−1.5	42.0	+1.0	42.0	0.0	43.5	+0.5	44.4	−1.0	48.0	0.0	52.5	−2.5	53.4	−2.6	53.3	−1.7	51.0	−1.0	48.9	−1.1	45.1	45.0
54° Humber . .	41.0	−1.8	40.3	−0.7	41.7	+0.7	42.2	+0.2	44.0	−0.3	47.7	−0.3	51.2	−1.8	55.7	−0.3	56.9	−0.1	56.1	+1.0	51.9	−0.1	48.6	+1.5	45.5	47.0
52° Shipwash .	44.7	−1.8	41.2	−1.3	43.1	−0.2	43.2	+0.4	46.7	+0.5	48.8	+0.1	54.2	−0.8	61.7	+0.3	63.2	+0.6	60.2	+1.1	56.9	+1.1	52.6	+1.7	47.9	47.5
Mean	42.2	−1.8	40.8	−1.1	41.8	+0.4	42.2	−0.1	44.5	0.0	47.1	−0.5	50.6	−1.1	55.7	−1.2	56.3	−1.4	55.2	−0.6	51.7	−0.7	48.5	+0.1	45.6	45.9
West Coast.																										
58° (Sea West of	*46.8*	*−1.2*	45.5	−0.8	44.4	+1.4	45.0	+1.5	*45.5*	*+0.5*	*49.0*	*+1.0*	51.9	−1.1	*52.0*	*−2.8*	54.0	−1.0	55.8	+1.8	54.2	+1.2	51.5	+1.5	47.5	44.5
56° Scotland) .	*46.3*	*−0.7*	45.4	−0.6	43.2	+0.2	43.0	0.0	43.4	−1.6	48.6	−0.9	51.8	−2.2	52.0	−2.0	56.2	−1.5	55.3	+0.3	53.4	+1.4	49.7	+1.7	46.7	46.0
54° Port Erin .	48.1	−0.2	46.1	0.0	44.2	−0.3	43.8	−0.5	45.2	−0.5	48.5	+0.1	50.9	−0.2	54.5	−0.9	56.3	−1.0	57.0	+0.8	54.6	+0.6	52.1	+1.5	47.7	47.5
52° Barrells . .	48.7	+1.2	46.2	−0.4	45.3	−0.6	45.6	+0.1	47.7	+1.1	50.0	+0.7	53.1	+0.6	56.2	+0.8	58.0	+0.6	57.9	+0.5	56.9	+1.9	53.7	+2.1	49.1	48.5
Mean	47.5	−0.2	45.8	−0.5	44.3	+0.2	44.4	+0.3	45.5	−0.1	49.0	+0.2	51.9	−0.7	53.7	−1.2	56.1	−0.7	56.5	+0.9	54.8	+1.3	51.8	+1.7	47.8	46.6
South Coast.																										
51° Royal Sovereign	48.1	+0.2	43.9	−1.6	43.6	+0.1	45.3	+1.3	47.6	+1.7	51.0	+0.8	55.5	+0.5	60.9	+2.0	62.5	+0.8	62.5	+1.5	58.9	+1.5	53.7	+0.9	49.5	48.9
50° Seven Stones	52.0	+1.6	*49.7*	*+0.1*	50.0	+1.1	49.5	+0.5	50.7	+1.3	53.4	+1.5	55.5	+0.4	60.6	+2.7	61.6	+2.0	60.3	+2.4	57.6	+2.2	54.3	+1.3	52.7	51.0
Mean	50.0	+0.9	46.8	−0.8	46.8	+0.6	47.4	+0.9	49.1	+1.5	52.2	+1.1	55.5	+0.5	60.8	+2.4	62.0	+1.4	61.4	+1.9	58.3	+1.9	54.0	+1.1	51.1	50.0
Long. W.	South-West, *i.e.*, Mouth of Bristol Channel and S. of Ireland. Lat. 51°N.																									
5° Hartland . .	46.4	+1.9	46.3	+2.0	47.3	+3.0	45.5	+2.3	50.1	+1.9	54.0	+2.2	57.7	+0.9	61.0	+1.0	62.4	+1.3	59.6	+2.4	57.0	+2.5	52.5	+1.9	51.0	50.3
8° Daunts Rock	47.7	+2.7	47.4	+3.9	47.7	+4.8	47.4	+4.1	48.0	+2.5	52.4	+2.9	54.0	+1.4	55.5	−0.8	58.2	+0.6	58.5	+2.4	55.9	+2.8	50.9	+2.5	50.0	49.5
Mean	47.1	+2.3	46.9	+2.9	47.5	+3.9	46.5	+3.2	49.1	+2.2	53.2	+2.6	55.9	+1.2	58.3	+0.1	60.3	+1.0	59.0	+2.4	56.5	+2.7	51.7	+2.2	50.5	49.9

The Means of Sea Temperature for 12 months are:—East Coast 48.1°; West Coast 50.1°; South Coast 53.7°; South-West 52.7°.

* Sea surface temperatures compared with air temperatures observed at adjacent land stations.

TABLE II.—LIST OF NEW STATIONS FURNISHING PLANT, BIRD AND INSECT RECORDS, WITH THE NAMES OF THE OBSERVERS, 1928.

The numbers in brackets following the District Letters represent the Meteorologi cal Office designations.

The stations listed below have not reported for 1928:—A 1c, 2a, 6b, 8d, 20b, 21c, 21e, 22a, 25e, 28f, 32b, 32e, 33a, 35c. B 37a, 38c. C 4f, 5f, 7b, 17d, 22f, 22g, 22h, 23a, 25b, 28a. D 9a, 9c, 18a, 21b, 21d, 28b, 35b, 37b, 41b, 44e. E 1b, 1g, 2a, 2b, 2d, 4c, 4j, 4n, 8c, 10e, 14b, 14c, 27c, 28c. F 19a. G 41a, 41d. H 20a. I 11d, 19a, 25a, 25b, 25d, 38a, 39a. J 6a, 10a, 15a, 38a, 39c.

It is hoped that some of these are only temporarily interrupted, while in some cases the observers have moved but are continuing to observe at new stations.

The following stations were absent in 1927 but have now resumed observations:—B 33a. C 18b, 21b, 22e. D 16e, 17a. G 35d. I 8a. K 5a. Though included in the total numbers of new stations given below, they are not shown in the list as full particulars will be found in the 1926 list.

In the list of new stations given below those marked † are old stations absent in 1926 and hence omitted from the complete list of stations then published. An asterisk after an observer's name indicates a Fellow of the Royal Meteorological Society.

STATION.	COUNTY.	Height above Sea-level.	OBSERVER.
A (8).			Observers: 82−14+17=85.
0f. Guernsey	Chan. Isles		L. le Tocq.
1d. Carbis Bay	Cornwall	120	Rev. A. Thornley,* M.A., F.L.S., etc.
8e. Plymstock	Devon	210	L. P. Morris.
9d. Tresmeer	Cornwall	600	W. J. Smith and Scholars.
11h. Widecombe-in-the-Moor	Devon	900	Miss B. Chace.
12f. Kilkhampton	Cornwall	580	H. H. Griffin.
†12b. Bideford	Devon		E. C. Hope Hall.
15d. Sidford	Devon	120	S. W. Toms.
15e. Lyme Regis	Devon	200	J. E. Clark.*
17f. Ilfracombe	Devon	150	Miss M. E. Bunyard.
21f. West Moors, Wimborne	Dorset	50	S. D. Cox.
22c. Street	Somerset	50	J. E. Clark.*
25i. Pilton	Somerset	200	C. E. A. Armitage, M.A., M.B.
28g. Griffithstown	Monmouth		F. A. Williams.
32f. Penally	Pembroke		F. P. Ramsden.
34e. Laugharne	Carmarthen	50	J. F. Thomas.
43d. Aberystwyth	Cardigan	250	Miss A. Robinson.
B (10).			Observers: 20−2+7=25
19a. Ballingarry, Rathkeale	Limerick	350	Mrs. G. F. Hamilton.
34f. Kilkenny	Kilkenny		Miss Gorringe.
37b. Killinick	Wexford	80	S. Tanner.
42d. Hacketstown, Rathvilly	Carlow	590	Rev. C. S. S. Ellison.
51a. Dalgany, Greystones	Wicklow	200	D. J. Evans.
52a. Portmarnock	Dublin	0	E. O'Mahony.
C (5).			Observers: 73−10+16=79.
4g. Romsey	Hants		H. Philpot.*
7i. Bishopstoke	Hants		H. H. G. C.
10f. Portslade	Sussex	0	E. C. Smith.*

11e. Chiddingfold	Surrey	180	Miss M. R. Morley.
12b. Chilbolton	Hants		T. H. Harrison.
15g. Hassocks	Sussex	200	Miss S. Salisbury.
18g. Hellingly	Sussex	100	W. H. A. Heald.
18h. Mayfield	Sussex		Lt.-Col. A. H. Wolley-Dod.
19d. Sutton	Surrey	350	Mrs. Faulkner Jefferis.
21c. St. Leonards	Sussex		L. A. Collins.
25e. Lenham	Kent	620	A. E. Webb.
25f. Sutton Valence	Kent		M. E. Lucy.
25g. Bearsted	Kent	100	Miss K. M. Green.
D (4).			Observers: 70 − 10 + 18 = 78.
9d. Bourton-on-the-Water	Gloucester	440	H. H. Albino.
10e. West Malvern	Worcester	800	N. W. Thomas.
10f. West Malvern	Worcester		Miss Gillespie.
11d. Church Stretton	Salop	650	J. E. Clark.*
12a. Chirbury	Salop	500	Capt. C. S. Price-Davies.
15d. Pillerton Hersey	Warwick	260	J. L. Hodgkinson.
17c. Uffington	Salop	250	E. R. Sequeira.
17d. Benthall, Broseley	Salop	600	G. Potts.
23a. Wem.	Salop	270	E. W. Bowcock.
†24c. Olney	Bucks		E. G. Allen.
29a. Kirby Muxloe	Leicester	310	Miss O. S. Wilshere.
29b. Loughborough	Leicester		R. G. Burder.*
37c. Staunton	Notts		Miss F. K. Staunton.
38b. Mansfield	Notts	400	The Brunts School.
44f. Ackworth, Pontefract	Yorks W.R.	110	Miss P. H. Arundel.
49d. Kirk Deighton, Wetherby	Yorks W.R.	550	B. C. Boswell and Scholars.

E (3).			Observers: 51 − 14 + 8 = 45.
1h. Elstree	Herts	400	E. Greenwood.
1i. Barnet	Herts	440	R. A. Woolner.
2c. Aldbury, Tring	Herts	450	Mrs. M. Dale.
3c. Enfield	Middlesex	100	Miss J. Atkinson.
3d. Warley	Essex	300	L. Lanspeary.
11f. Cambridge	Cambridge	50	Mrs. H. M. Rait Kerr.
13c. Frinton	Essex		G. S. Cansdale.
26c. Blofield, Norwich	Norfolk	50	Miss S. E. G. Harker.
F (7).			Observers: 33 − 1 + 18 = 50.
1c. Aberhavesp, Newtown	Montgomery	400	R. Davies.
2c. Aberdovey	Merioneth	0	Mrs. M. C. Debenham.
2d. Aberdovey	Merioneth	150	L. W. Rees.
7a. Montgomery	Montgomery	350	R. Williams.
9d. Trefriw	Carnarvon	100	E. M. Crewe.
11g. Dyserth	Flints	300	Mrs. J. G. Pidduck.
11h. Abergele	Denbigh	20	C. E. Jarrett.
13f. Caerestyn, Caergwrle	Flints	330	C. Phillips.
13g. Chester	Cheshire		F. P. Dodd Thomas.
14d. Stockton Heath, Warrington	Cheshire	200	J. Roy.
†15a. Southport	Lancs		Miss Langdon.
16d. Alderley Edge	Cheshire	360	Mrs. H. D. O'Hanlon.
16e. Prestbury	Cheshire	400	Lieut.-Colonel Abercrombie, C.M.G., and R. M. Garnett.
18b. Marton Mere, Blackpool	Lancs	30	R. S. France.
23a. Santon Bridge, Nether Wastdale	Cumber.	100	J. A. G. Barnes.

TABLE II.—LIST OF NEW STATIONS FURNISHING PLANT, BIRD AND INSECT RECORDS, WITH THE NAMES OF THE OBSERVERS, 1928—*continued.*

STATION.	COUNTY.	Height above Sea-level.	OBSERVER.
24a. Arnside	Cumber.	30	J. A. G. Barnes.
28d. Keswick	Cumber.		W. W. Strang.
31b. Carlisle	Cumber.		R. Graham.
			Observers: 18−2+3=19.
G (9).			
35e. Warrenpoint	Down	0	Rev. W. F. Johnson.
55b. Ballymoney	Antrim	200	J. L. Nevin.
			Observers: 11−1+14=24.
H (6).			
2b. Claunch, Sorbie	Wigtown	100	A. C. McCardlish.
11a. Collin, Racks	Dumfries	50	S. G. McAlpine.
17a. Eastriggs, Annan	Dumfries	0	R. J. Liddle.
18a. Dumfries	Dumfries	70	W. Semple.
18b. Lockerbie	Dumfries	220	R. Dickson.
18c. Closeburn, Thornhill	Dumfries	220	J. K. Greig.
18d. Keir Mill, Thornhill	Dumfries	220	J. Maxwell.
20b. Hareshawmuir Kilmarnock	Ayr	600	E. R. Paton, M.B.O.U.
21a. Ardnadam, Holy Lock	Argyll	100	P. G. Satow.
23a. Armagour, Coll	Argyll	50	J. H. Richardson.
27d. Carluke	Lanark	850	G. Gray.
27e. Lesmahagow	Lanark	550	Lesmahagow Ranger Co.
27f. Glasgow	Lanark		N. Hopkins.
30a. Cairndow, Inveraray	Argyll	0	Miss A. Munro.
			Observers: 33−7+7=33.
I (2).			
5c. Sleaford	Lincs		J. & H. Hindley.
6b. Kexby, Gainsborough	Lincs		A. E. Page.
11f. Limber, Habrough	Lincs	100	R. May.
26b. Falstone	Northumb		Rev. A. J. Dexter.*
30b. Goathland	Yorks N.R.		W. S. Medlicott.
38d. Little Mill, Alnwick	Northumb	120	J. M. Craster.
			Observers: 19−5+2=16.
J (1).			
36c. Keith	Banff	500	G. Henderson.
36d. Aberlour	Banff	350	J. G. White.
			Observers: 8−0+5=13.
K (0).			
18b. Strome Ferry	Ross	40	Miss A. Fraser.
18c. Shieldaig, Loch Torridon	Ross	750	D. Matheson.
24e. Beauly	Inverness	0	Major R. D. C. MacLeod.
43a. Cara, S. Ronaldshay	Orkney	10	S. Louttit.
43b. Finstown, Kirkwall	Orkney	100	A. Wood.

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928.

(For Latin names see Table V.).

STATION.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.	Ivy.
) Channel Isles, Guernsey,															
a. Les Blanches	112	*30*	*38*	*61*	68	105	106	108	113	156	186	*190*	183	...	252
Jersey.															
e. Westmount .	121	*50*	63	80	86	*110*	100	110	146	141	*189*	*193*	*186*	...	270
A (ii.) (8)															
f. Phillack, Hayle .	123	41	54	*75*	80	116	135	122	145	157	182	*188*	183	...	254
a/b. Polperro .	115	25	*32*	*62*	65	93	118	121	112	155	201	*202*	192	221	251
a. Duloe . .	116	23	27	57	81	*99*	111	122	153	165	170	*188*	196	213	259
c. Lopwell .	137	46	69	99	106	*120*	139	*140*	157	169	190	*202*	203	225	281
b. Buckfastleigh	129	46	72	93	96	*106*	124	124	*147*	*156*	*182*	*198*	204	...	...
e. Plymstock .	133	47	63	95	101	112	136	*136*	156	163	194	193	198	235	278
a. Launceston .	126	40	77	96	*84*	102	129	127	137	162	170	*188*	196	210	269
c. Clawton .	131	48	*81*	103	81	115	131	122	157	160	184	200	194	202	282
d. Newton Abbot .	118	38	38	*71*	*87*	104	116	116	152	143	179	*189*	*188*	...	...
e. Teignmouth.	130	50	*58*	*88*	97	120	123	131	151	156	188	*197*	196	...	275
f. Okehampton	119	22	48	64	83	98	121	129	*141*	*156*	*177*	*190*	*193*	...	287
g. Colebrooke .	128	47	51	95	108	121	100	*113*	150	157	*186*	*200*	203	...	...
f. Kilkhampton	123	40	*50*	91	84	*111*	128	103	134	*155*	192	*199*	*195*	...	...
a. Exmouth .	114	22	49	71	73	100	114	116	138	149	168	*181*	*183*	237	266
a. Umberleigh .	119	35	57	78	70	99	*123*	126	*142*	158	*170*	*184*	*187*	...	...
b. Bishop's Tawton	116	23	37	80	103	92	122	124	138	154	163	*178*	182	223	281
c/e Lyme Regis	118	32	36	92	64	108	121	121	145	156	*171*	*185*	*188*	...	284
*. Combe Martin	112	9	41	*60*	64	95	117	117	148	145	176	*186*	185	217	247
f. Ilfracombe .	120	47	48	*67*	76	100	*121*	121	134	158	188	*193*	187	209	269
a. Weymouth .	126	*45*	*59*	78	84	117	130	116	150	160	*176*	*196*	*206*	...	261
f. Staplegrove .	117	21	*55*	86	72	99	105	120	*134*	*146*	*172*	*192*	202†	...	...
d. Broadstone .	127	48	72	84	64	*105*	125	127	156	154	*176*	*203*	209	...	...
b. Flax Bourton	114	11	45	80	87	97	121	120	125	151	159	*180*	187	204	242
5c. Keynsham .	122	43	63	77	92	101	121	115	148	153	*178*	187	185	...	...
5f. Pensford .	127	41	52	69	105	119	120	*123*	153	155	188	*200*	196	...	273
7c. Portishead .	116	24	45	74	74	100	120	124	140	*151*	168	189	183	223	264
7d. Long Ashton	114	20	45	*68*	87	97	121	120	125	151	159	*183*	187	...	242
A (iii.)															
8c. Cardiff .	126	30	57	82	97	120	122	122	150	167	183	*193*	192	...	275
8g. Griffithstown	126	50	50	*73*	*98*	*112*	124	127	*152*	160	*176*	201	*188*	...	...
a. Bridgend .	121	38	46	64	100	105	124	129	154	159	171	*183*	184	225	269
a. Mumbles .	125	42	52	78	*90*	120	104	127	*149*	155	*174*	*196*	207	230	258
2a/b. Tenby .	113	*15*	17	*56*	84	111	122	125	127	159	172	*184*	*185*	...	250
2d. Lamphey .	116	36	58	79	*90*	*104*	*117*	110	124	146	*170*	*179*	*176*	...	...
4c. Philadelphia.	121	28	55	76	88	109	117	124	123	154	192	*197*	192	...	257
5b. Mathry .	126	47	65	*69*	79	*106*	*120*	120	159	150	*200*	*203*	*195*	...	...
0a. Abergavenny	121	40	40	66	102	116	126	126	134	161	172	*184*	186	...	271
0b. Cwm, Crickhowell	137	43	66	115	94	*116*	*133*	139	160	169	199	*206*	*210*	...	...
3a. Hafod .	140	64	52	115	103	*119*	134	132	172	164	201	207	217	...	244

* Combination of the three stations, 17a, b, c.
† Observed at Crowcombe, 10 m. distant.

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928—*continued.*

STATION.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.
43.* Aberystwyth	119	37	55	74	75	97	123	125	133	148	178	194	*194*	233
44a. New Radnor .	133	58	50	100	109	114	123	144	165	154	189	199	197	...
B (10)														
4a. Darrynane Abbey .	118	40	47	80	55	87	100	120	149	157	188	*193*	196	215
6a. Timoleague .	117	13	38	*70*	63	*97*	117	123	134	161	187	*196*	203	219
14b. Passage West	130	50	*71*	*93*	93	*120*	121	133	*135*	151	202	*200*	*196*	...
22b. Castle Lyons	122	39	57	71	69	119	119	118	135	159	195	195	188	215
27a. Castleconnell	125	*26*	58	61	85	115	127	129	152	160	193	*198*	201	222
27b. Corbally, Limerick .	125	*28*	*60*	66	80	*115*	122	125	135	172	*193*	*200*	*204*	...
30a. Cashel .	126	*30*	*62*	54	93	*115*	127	130	138	161	191	*200*	206	222
34b/f. Kilkenny .	124	25	72	71	91	115	125	129	*138*	155	*191*	*190*	185	...
38a/b. Borris .	131	39	24	94	94	121	132	131	144	172	205	*207*	206	210
42d. Hacketstown .	132	37	*36*	*91*	107	*117*	130	136	147	170	*200*	*207*	*210*	...
43a. Mountmellick	122	36	37	*77*	94	101	124	131	136	154	183	*194*	202	211
C (5)														
1.† Bournemouth	125	*45*	*40*	*85*	90	113	122	131	152	157	*82*	204	183	220
1j. Southbourne.	120	43	38	84	82	110	118	118	136	152	*182*	198	183	...
1b. Ringwood .	119	20	*60*	81	86	97	116	116	137	153	174	*200*	187	...
1c. Lymington .	122	39	64	88	86	106	109	121	127	147	188	203	188	228
1i. Appleslade .	123	32	61	88	76	116	*118*	118	135	155	191	*200*	*186*	205
2a. Mere .	125	51	59	78	86	104	127	124	151	159	182	*195*	184	...
3a. Shanklin .	121	25	57	88	76	*103*	129	118	137	153	*180*	*195*	192	...
3e/f. Southsea .	122	35	58	78	70	109	122	128	141	157	184	191	196	227
3g. Newport .	122	40	63	74	80	108	123	137	133	162	177	188	175	...
4b. Sherfield English	114	22	49	58	78	98	117	117	135	143	166	195	188	217
4c. Stratford sub-Castle .	123	*30*	*50*	*75*	94	96	127	125	157	158	189	190	187	233
5d. Bratton .	122	40	48	77	85	102	122	126	147	150	176	200	188	237
5e. Steeple Ashton	124	49	*50*	78	95	*100*	119	117	153	156	*180*	*200*	*188*	...
6a. Havant .	116	23	42	64	89	95	118	123	130	151	182	*200*	180	...
6c. Chichester .	123	30	60	*70*	85	109	122	120	151	153	185	200	195	221
6d/e. Hayling Island	121	30	50	72	85	102	117	117	140	153	198	*200*	182	...
7a. Botley .	120	17	46	63	*85*	*110*	124	122	130	151	189	...	203	...
7c. Hythe, .	123	25	*50*	*70*	*90*	115	*120*	*130*	145	147	186	190	195	229
7h. Winchester .	125	*50*	50	84	*90*	101	125	125	154	150	*186*	*190*	*195*	...
8b. Marlborough	124	*40*	49	63	88	*110*	*125*	138	133	160	*190*	*195*	196	191
10c. Littlehampton .	126	42	50	86	94	110	112	128	*150*	161	198	180	202	...
11b. Newton Valance .	124	44	53	63	95	114	123	129	150	154	183	*195*	*190*	...
11d. Grayshott .	126	37	*50*	95	97	118	124	*127*	*151*	*158*	*178*	186	191	...
11e. Chiddingfold.	126	*40*	*50*	*90*	*95*	115	125	125	152	163	172	204	182	...
13a/b. Swindon .	125	40	49	71	88	103	122	122	154	161	188	204	199	...
15e. Lower Beeding .	120	22	*45*	72	*85*	109	115	118	143	155	180	*195*	*200*	193
13f. Cowfold .	117	22	48	57	82	97	122	119	139	148	*180*	193	*200*	...

* Combination of the three stations, 43b, c, d. † Ditto of 1a, e, f.

ABLE III.—Date (Day of Year) of First Flowering of Plants, 1928—*continued.*

Station.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.	Ivy.
5g. Hassocks .	120	37	37	75	75	105	121	119	155	155	167	190	204	...	271
6b. Farnham .	119	24	49	77	*80*	108	124	116	143	148	177	*195*	191	...	261
6f. Odiham .	123	30	51	79	86	115	119	123	147	149	193	*195*	193	...	274
6g. Rowledge .	122	17	43	85	96	116	123	124	134	157	177	*195*	193	...	...
6i. Churt .	123	23	*45*	89	83	106	126	126	141	160	174	199	*200*	...	259
6m. Godalming .	121	*35*	*40*	65	85	98	123	125	146	151	189	*197*	198	...	274
6n. Normandy, Guildford .	124	41	51	75	86	114	119	120	146	155	195	196	194	228	...
8a. Lewes . .	115	43	38	68	70	98	116	119	130	148	159	200	*195*	224	...
8b/g. Hellingly .	121	46	50	72	87	102	122	131	135	*150*	*165*	*200*	*195*	...	...
8c. Ditchling .	118	33	28	76	98	110	125	123	132	150	162	200	180	...	294
8e. Waldron .	128	48	*50*	82	95	*110*	123	126	151	157	199	*198*	*195*	235	...
8f. Coleman's Hatch .	126	36	52	78	99	113	121	119	156	160	*185*	194	202	226	281
8h. Mayfield .	120	21	*50*	70	83	106	119	119	149	158	*185*	*195*	190	...	...
9d. Sutton .	120	48	52	83	84	94	116	117	136	154	*190*	180	*190*	...	274
0a. Reading .	121	*40*	63	*80*	84	94	119	121	137	152	175	*195*	190	...	277
1d. Rye . .	125	31	49	70	92	111	127	123	152	162	193	*195*	200	...	272
2a. Lingfield .	120	14	56	64	96	97	119	*125*	*145*	*155*	178	*195*	*200*	218	292
2b. Warlingham .	121	30	37	63	93	104	122	*125*	143	154	*185*	*195*	*200*	...	...
2c. Purley .	125	31	45	76	*95*	114	118	122	148	151	193	198	203	227	...
2i. Croydon .	126	37	39	92	*95*	112	122	122	*150*	159	*195*	*195*	192	...	...
4b. Woodchurch	123	32	*40*	67	86	*110*	121	121	153	160	*190*	*195*	*200*	...	...
5d. East Malling	124	*40*	51	86	*90*	99	123	119	142	145	191	*200*	202	...	271
5e. Lenham .	128	47	54	75	91	113	127	127	139	163	190	214	196	229	281
5g. Bearsted .	120	43	50	64	95	95	120	120	125	154	177	217	185	...	265
6d. Sydenham .	123	20	50	79	80	116	*119*	*120*	147	*160*	*185*	*200*	197	...	285
7a. Whitstable .	126	49	65	*75*	83	112	113	119	144	159	*185*	*200*	205	...	265
9b. Sandwich .	123	40	51	61	90	112	*124*	125	145	149	*185*	*200*	*195*	...	272
D (i.) (4)															
1c. Wotton-under-Edge.	126	38	51	94	94	111	124	122	155	155	185	191	188	...	259
3b. Ross .	119	*30*	44	76	93	93	122	119	133	151	*185*	*190*	*190*	...	...
4a. Weobley .	124	21	43	100	93	102	116	126	153	156	*180*	*200*	*195*	...	...
4d. Staunton-on-Arrow	125	43	59	64	92	106	119	125	152	156	182	205	194	...	258
5d. Coaley .	121	39	43	80	89	101	125	123	139	153	175	185	194	202	265
6a. Dymock .	123	44	58	74	87	102	131	127	*150*	*160*	*180*	*185*	183	...	...
6b. Bromyard .	136	45	82	90	100	125	*135*	141	160	168	*185*	203	*200*	...	259
6c. Kimbolton .	130	48	57	84	99	*122*	*130*	129	*150*	158	*180*	*200*	*200*	...	...
6d. Colwall .	126	37	49	*84*	*97*	*120*	127	126	143	154	175	201	201	...	274
9b. Bourton-on-the-Water .	130	40	64	84	95	118	127	122	162	162	186	*200*	*200*	...	258
10d. Offenham .	125	52	57	*85*	87	109	117	119	136	157	*180*	*195*	*200*	...	...
10e/f. West Malvern	128	49	46	74	107	106	129	133	156	157	181	193	203	...	270
11a. Tenbury .	125	39	29	85	99	102	127	124	155	155	183	205	194	...	263
16b. Cookley, Wolverley .	129	42	79	*85*	102	111	*125*	125	*150*	161	*185*	193	*195*	...	269
16f. Frankley .	131	48	47	84	106	*115*	133	146	*150*	167	*183*	192	*195*	232	276
17a. Edgmond .	128	45	46	*85*	100	116	130	131	147	*160*	*183*	196	*195*	...	...
18b. Oswestry .	135	*45*	71	95	108	117	136	134	154	*160*	202	*200*	202	...	...
18c. Gobowen .	126	40	48	89	97	113	129	*125*	148	157	179	185	199	...	275

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928—*continued.*

STATION.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.	Ivy.
D (ii.) (4)															
10c/d. Ashorne	125	*37*	*55*	84	96	114	126	124	*145*	152	190	191	190	...	272
13b. Gerrards Cross	123	32	49	66	85	105	*125*	134	146	158	*190*	*195*	*195*	...	273
13d. Beaconsfield	128	45	68	96	94	107	123	128	147	154	*175*	*200*	*195*	...	...
14a/b. Oxford	119	29	49	78	80	97	118	116	142	153	171	200	190	...	257
15c. Stratford-on-Avon	128	49	*85*	*85*	91	112	131	121	151	156	184	213	187	233	275
15d. Pillerton Hersey	129	53	*55*	*85*	93	110	126	127	154	*155*	*185*	*200*	204	...	...
19b. Granborough	123	30	*50*	65	88	102	131	126	*145*	156	*185*	*200*	*200*	...	265
19d. Weston Turville	129	*30*	*55*	100	92	120	133	126	145	156	*185*	*200*	*200*	...	...
20a. Farnborough	122	19	26	77	99	114	128	120	143	155	187	198	201	...	254
21h. Blackdown	129	29	63	89	89	114	132	126	154	164	*187*	*204*	*196*	...	...
21i. Yardley Wood	131	52	53	85	101	111	132	129	158	169	187	207	191	...	...
24a. Bletchley	129	46	66	95	101	*110*	130	118	*155*	161	186	188	192	...	273
24b. Northampton	125	*45*	60	*80*	86	113	131	126	154	158	180	*185*	185	...	257
26b. Sutton Coldfield	134	48	59	103	*90*	121	132	126	*155*	176	193	198	202	...	...
28a. Little Harrowden	119	31	23	74	85	111	126	121	151	151	188	184	186	...	255
34a. Kegworth	131	30	66	87	96	109	132	141	158	162	196	197	202	221	280
38a. Hodsock	129	31	66	88	101	117	122	123	156	164	181	210	186	...	281
38b. Mansfield	126	41	43	78	103	109	137	110	126	172	191	200	202	...	...
D (iii.) (4)															
30a. Mayfield	128	40	47	70	102	117	131	129	157	164	186	*195*	193	...	...
35a. Somershal Herbert	132	16	64	96	102	115	129	132	154	*165*	199	208	*200*	226	...
39b. Kirkheaton	139	*60*	53	*100*	*110*	*120*	151	132	162	179	199	292	199	232	...
39d/e. Sheffield	137	50	49	101	*110*	*125*	141	142	164	176	*190*	195	*200*	...	291
41d. Crosshills	134	43	51	92	99	124	133	140	150	172	189	200	201	210	270
42a. LowBentham	130	42	49	78	117	*125*	*130*	132	*155*	160	175	199	*200*	...	265
44f. Ackworth	134	60	50	100	115	119	136	131	154	162	175	199	202	229	...
45a. Overton	137	43	67	74	116	*125*	*130*	134	*160*	178	208	211	*200*	...	302
45b. Altofts	133	54	57	*85*	*115*	130	132	131	164	165	172	191	*195*	...	...
49a. KirkDeighton	129	39	45	79	114	115	128	125	155	*165*	185	*195*	199	...	...
E (3)															
1*. Barnet	125	38	55	*90*	97	107	125	128	144	160	*182*	*188*	*188*	...	...
2e. Aldbury	119	10	32	89	89	92	125	122	157	155	186	185	186	...	282
3c. Enfield	125	25	57	*90*	91	*110*	125	125	150	157	*190*	*190*	*190*	...	...
3d. Warley	118	27	48	92	92	113	119	*125*	148	148	*185*	*190*	*190*	...	...
4b. Knebworth	124	26	52	78	102	115	*120*	*120*	135	147	*185*	*190*	*190*	...	...
4h/i. Hitchin	121	27	37	85	84	114	124	120	144	152	178	191	*190*	...	261
4k. Pirton	123	*50*	51	*80*	84	*105*	121	124	152	152	*185*	*190*	180	...	269
4m. Luton	125	53	47	*80*	86	104	130	125	154	155	187	*190*	*190*	...	...
5a. Turvey	125	23	64	74	86	103	127	126	154	152	196	191	200	...	294
7a. Birch Green	118	26	43	74	89	91	122	116	131	152	*190*	197	188	215	...
7b. Sawbridgworth	123	24	49	84	93	109	126	121	138	156	186	197	188	...	287

* Combination of the three stations, 1d, f, i.

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928—*continued.*

STATION	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.	Ivy.
8a. Letchworth .	120	29	26	78	76	106	130	115	*145*	162	*190*	*195*	*190*	...	265
8e/f. Kempston .	123	22	53	77	94	100	114	124	147	155	202	202	191	210	283
10b. Halstead .	121	16	63	79	87	*95*	126	122	146	155	*190*	187	190	...	266
10f. Gt. Totham .	118	24	45	65	*90*	93	103	118	154	155	190	194	186	...	...
10g. Pleshey, .	124	41	57	*70*	*90*	114	127	120	150	150	*185*	*190*	*190*	...	...
11d/f. Cambridge .	123	44	47	67	95	*115*	117	139	146	148	183	*190*	190	...	278
12a. Keysoe .	125	39	68	77	84	111	112	122	147	151	192	197	202	...	275
13a. Lexden .	125	52	52	84	*90*	114	119	119	150	150	179	198	189	...	...
14a. Ballingdon .	121	21	50	78	93	108	119	125	145	158	176	*195*	188	...	273
22b. Langford .	131	51	*70*	94	97	114	129	126	157	163	187	192	*195*	219	263
22d. Grimston, Lynn	132	49	68	99	103	118	132	133	*155*	154	194	194	188	...	269
24a. Norwich .	129	*45*	*70*	77	98	114	120	121	148	159	*195*	*195*	201	...	...
24b. Postwick .	128	45	74	*80*	101	116	121	121	*155*	154	198	195	183	...	289
24c. Runhall .	135	39	*70*	*85*	106	124	132	141	*160*	167	*195*	195	202	226	275
25d. Hunstanton .	134	*45*	74	*80*	*105*	*125*	141	146	153	154	195	*195*	185	...	...
26a. Hemsby .	135	49	55	98	*105*	*120*	131	*149*	*160*	164	195	202	198	...	...
26b. Thurton .	130	*45*	*65*	*95*	100	120	*125*	*135*	158	161	180	193	181	...	...
26c. Blofield .	128	*45*	*65*	92	85	123	119	128	151	162	*185*	*195*	*190*	...	...
F (i.) (7)															
1b. Llaithddu	141	78	85	105	108	*115*	*134*	146	165	177	179	*204*	*201*	...	...
2c/d. Aberdovey .	123	32	55	87	99	101	118	122	123	151	196	196	190	191	260
7a. Montgomery .	134	45	*57*	84	101	*116*	*131*	131	153	167	*205*	*210*	*210*	...	...
9a. Beaumaris .	128	58	52	64	*108*	113	115	125	151	153	195	*200*	199	211	248
9c. Roe Wen .	130	36	64	82	96	*110*	123	126	147	*154*	204	*207*	*206*	...	254
9d. Trefriw .	130	43	58	86	101	110	*125*	123	*145*	158	*199*	*206*	*205*	216	...
10a. Wrexham .	122	33	44	67	101	103	122	128	139	142	189	196	*195*	...	...
11e. Dolben .	126	51	52	67	80	111	121	120	151	154	*198*	*204*	*203*	...	...
11h. Abergele .	133	46	54	85	*112*	122	124	141	152	152	*197*	*204*	*203*	...	264
13e. Flint Mountain .	132	*60*	*73*	92	116	*123*	128	127	*137*	152	*190*	196	*195*	...	...
F (ii.) (7)															
13c. Hr. Tranmere	122	14	40	*77*	95	*112*	131	126	154	152	182	188	188	...	...
13d. Shotwick .	128	44	57	77	*90*	106	129	128	153	147	202	*203*	198	...	282
14a. Barnton .	133	48	48	85	106	125	126	149	140	167	195	202	201	...	284
14b. Altrincham .	133	49	57	97	106	126	133	131	151	161	197	191	197	...	224
16b. Bramhall .	130	38	63	*92*	98	108	140	124	151	164	186	194	204	...	289
16d. AlderleyEdge	133	45	56	95	*104*	117	132	134	157	165	*192*	192	201	...	275
18b. Marton Mere	131	44	57	60	109	123	128	127	165	169	197	198	200	...	280
20a. Nelson .	135	43	64	95	101	120	134	141	162	172	193	195	204	230	279
21a. Leyland .	133	48	58	84	102	*121*	134	134	150	162	200	212	197	204	...
21c. Mitton .	134	44	75	81	110	114	*127*	135	*152*	*160*	198	*203*	*204*	...	...
22a. Urswick .	127	8	67	70	109	124	129	131	149	153	189	189	206	...	260
25b. Ambleside .	127	30	62	77	86	108	126	123	138	163	206	202	205	...	...
25d. Ellerbeck .	140	49	70	104	114	125	139	146	156	157	*208*	*207*	*200*	...	...
27a. Kendal .	136	59	66	97	104	123	127	134	153	162	206	207	190	...	280
28a. Keswick .	124	21	*50*	78	84	117	127	127	*138*	148	*198*	*197*	*200*	...	...
28b. Johnby Hall .	148	*62*	*80*	118	109	132	150	149	157	*178*	*215*	*216*	*213*	...	...
31b. Carlisle .	138	64	*63*	106	106	117	*128*	143	159	174	209	196	196	...	283
32a. Alston .	149	*52*	74	*104*	119	*129*	*145*	155	*160*	192	212	211	233	242	...

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928—*continued.*

STATION.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bind-weed.	Devil's Bit Scabious.	Ivy.
G (9)															
2a. Loughrea .	134	51	68	90	109	116	142	138	157	172	182	187	194	...	270
11a. Clogher .	128	59	77	94	88	*101*	129	126	146	157	*184*	*185*	191	222	279
18a. Farragh .	125	43	*58*	76	92	*99*	121	130	141	*166*	*188*	195	*190*	...	283
32b. Levally .	129	*32*	55	80	102	115	136	133	151	161	190	*194*	198	...	294
35c/e. Warrenpoint	129	25	65	86	97	95	130	129	153	170	203	200	195	218	271
41c. Scarva .	132	*41*	64	103	101	*109*	141	141	139	149	195	*200*	202	...	279
45a. Saintfield .	134	47	*69*	86	104	*108*	131	142	164	166	*198*	*199*	*198*	...	...
47a. Sixtowns .	132	37	57	85	102	*111*	140	142	156	157	206	*195*	*194*	208	266
50c. Belfast .	129	45	47	77	95	*100*	138	142	158	167	194	194	*192*	...	...
50d. Muckamore .	127	*40*	51	85	108	*105*	111	132	153	164	190	*191*	*188*	202	275
50g. Comber .	127	40	51	101	80	*105*	132	130	161	153	193	*193*	190	...	286
51a. Magherafelt .	135	48	67	99	97	*112*	140	142	153	161	194	*200*	203	...	289
54a. Hazelbank .	126	57	46	79	81	*97*	126	143	152	168	185	190	190	218	261
54b. Larne .	129	*38*	52	86	96	116	138	131	*151*	153	200	*195*	*197*	...	264
H (i.) (6)															
Isle of Man.															
0c. Lezayre .	132	*46*	64	78	99	*114*	128	128	164	160	207	195	197	...	...
0d. Peel .	127	*41*	43	67	101	*113*	126	128	*152*	153	211	195	190	...	270
H (ii.) (6)															
1a. Drummore .	136	46	69	96	106	119	139	142	158	167	195	198	201	...	279
2b. Claunch, Sorbie .	135	54	61	98	105	*123*	*143*	141	156	156	*197*	*194*	*190*	...	...
11a. Collin .	131	57	56	85	95	*120*	140	134	147	161	203	193	183	...	284
17a. Eastriggs .	129	*51*	*57*	*84*	*95*	*116*	134	131	147	161	181	190	192	...	...
18b. Lockerbie .	137	*58*	70	97	108	*124*	*144*	139	*158*	168	194	192	*190*	...	...
18d. Keir Mill .	134	*52*	*58*	*86*	*97*	*117*	129	139	158	156	215	192	206	...	...
20b. Hareshaw-muir	149	*55*	58	100	135	*140*	*145*	*150*	190	185	211	*206*	*215*	204	...
21a. Ardnadam .	137	49	*55*	94	119	*121*	*138*	132	158	167	*201*	199	*205*	...	...
27d. Carluke .	143	*60*	64	108	112	130	143	147	*167*	170	211	202	205	211	...
30a. Cairndow .	129	57	63	75	107	111	131	133	160	153	182	187	194	...	294
33c. Ledaig .	136	53	*65*	111	121	*125*	134	140	155	156	*189*	*187*	*193*	...	...
I (2)															
5c. Sleaford .	126	35	50	*75*	83	*99*	*114*	120	155	163	205	203	205	...	...
6a. Lincoln .	132	58	61	*88*	97	110	127	137	160	162	181	196	207	...	274
6b. Kexby .	140	54	75	95	112	129	141	143	*165*	167	*187*	*201*	*208*	...	...
9a. Ashby . .	125	41	32	79	96	115	126	119	159	159	187	189	196	207	262
9b. E. Stockwith	130	52	62	*82*	91	*108*	133	127	154	161	*193*	206	194	...	...
11c. NewWaltham	130	42	64	78	92	100	131	131	152	165	190	203	211	...	260
11f. Limber .	134	34	57	86	101	106	133	132	164	183	205	203	*206*	...	297
12a. Holderness .	137	57	51	99	94	131	134	138	149	175	209	209	200	230	257
13a. Osgodby .	134	48	49	*97*	107	123	138	132	157	168	188	*200*	202	...	276
21a. Hull . .	136	55	65	95	104	118	135	128	162	162	202	205	198	...	278
21b. Skidby .	133	58	61	92	*95*	99	141	140	155	163	192	202	*202*	...	296
23a. Thirsk .	133	32	61	99	99	115	134	130	*161*	168	*192*	*203*	*204*	...	...
24b. Darlington .	133	49	51	84	102	117	134	134	158	169	189	199	208	211	277
25c. Corbridge .	145	64	84	96	*114*	129	154	149	*165*	*177*	*200*	200	*209*	...	...
26a. Catcleugh .	155	*66*	78	109	139	*141*	*158*	159	*175*	189	213	212	*215*	...	...
33a. Lanchester .	142	39	57	93	117	122	154	156	162	179	207	204	*213*	...	...
33b. Chopwell .	135	42	51	88	103	112	144	147	162	175	200	196	200	198	284
33c. Chester-le-Street .	139	42	37	95	*110*	*117*	145	141	*168*	184	*209*	205	*212*	211	...

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1928—*continued.*

STATION.	Mean Value excluding Scabious and Ivy.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Devil's-Bit Scabious.	Ivy.
5a. S'ton Delaval	136	45	39	93	109	*117*	*145*	146	*162*	178	197	201	199	226	...
6b. Cockle Park .	145	50	63	*105*	119	117	159	153	*166*	180	211	*206*	*209*	...	...
8c. Lemmington	150	64	81	108	119	127	151	150	168	178	223	209	*217*	235	308
J (I)															
2a. Broughton .	145	*60*	68	108	*122*	*128*	154	151	165	170	*208*	*205*	*206*	...	...
4a. Selkirk .	140	*48*	58	92	114	127	*147*	144	162	*171*	*208*	*204*	*205*	...	...
6b. Jedburgh .	140	48	*64*	*95*	*112*	125	*142*	138	*160*	172	*210*	*202*	217	...	299
3a. Stirling .	139	35	*55*	*95*	129	*125*	139	149	164	*171*	*205*	204	*203*	...	...
3c. Gargunnock .	144	69	*71*	108	*133*	141	141	143	*159*	166	*201*	*201*	*200*	...	...
0a. Loch Tummel	155	65	92	*111*	124	*140*	159	162	*180*	*188*	*212*	*214*	*213*	...	...
1a. Dundee .	139	52	54	100	*121*	*126*	146	141	159	168	*197*	202	*197*	...	286
6a. Cabrach .	155	82	93	101	119	129	153	166	183	191	211	215	*212*	216	...
6c. Keith .	154	55	63	114	129	*144*	167	164	189	187	*213*	213*	*211*	...	...
6d. Aberlour .	143	57	85	88	121	*128*	*143*	*154*	*159*	178	*204*	*201*	*202*	...	...
9a. Dunlugas .	147	65	63	101	129	129	150	159	161	185	208	202	208	...	282
9b. Forglen .	148	52	*61*	98	125	140	148	161	170	187	213	212	208	227	...
K (o).															
8a/b. Loch Carron	138	*52*	*67*	*100*	*114*	*125*	140	131	154	154	211	*206*	203	221	...
4c. Muir of Ord.	141	60	79	*100*	117	*135*	160	128	162	169	*195*	193	*193*	...	...
7b. Kirkhill .	144	63	83	101	101	*126*	157	155	163	173	*203*	*200*	*200*	...	...
otal records used	3419	290	290	263	312	233	315	340	265	305	196	152	181	83	194
Sub-District Means.															
(i) Channel Isles	...	...	(36)	[80]	72	(106)	108	112	(129)	(149)	[186]	...	(181)	...	(261)
(ii) Eng. S.W. only	122	35	52	84	82	105	122	121	141	156	180	192	193	218	266
(iii) S. Wales .	126	42	53	84	91	109	123	128	144	157	183	200	196	229	259
(i) Eng. W. Mid.	127	41	54	85	98	109	126	126	150	158	184	196	195	(217)	268
(ii) Eng. E. Mid..	126	37	55	84	93	111	127	125	148	159	185	198	194	(227)	269
(iii) Eng. N. Mid.	134	46	54	89	109	120	137	135	160	170	188	200	199	224	284
(i) N. Wales .	128	45	59	85	102	109	123	129	147	156	193	196	(195)	206	259
(ii) Eng. N.W. only	133	41	61	88	105	119	132	135	153	163	197	197	201	225	274
(i) Isle of Man .	...	...	54	(73)	(100)	...	(127)	130	[164]	(157)	207	(195)	(193)	...	(269)

* Observed at Loch Oive, 12 m. NW.

(*Continued from page* 229.)

THE HEVINGHAM RECORDS again provide valuable additional information for the earlier months, especially this time as to very early leafing notably of hawthorn, −52 days. Again, as in 1926/7, the snowdrop alone was later than the average. The flowering of wood anemone, 16 days early on March 2nd, again testifies to the effect of February warmth, and so too the "yellow butterfly" (brimstone), 27 days early on March 3rd. As in 1927 the 7 events in our Tables III-VI in District E, compared with 7 covering the same period at Hevingham, are later by 3 days.

TABLE IV.—ADDITIONAL FLOWER RECORDS, ETC.

DISTRICT.	Winter Aconite (*E. hiemalis*).	Snowdrop (*G. nivalis*).	Yellow Crocus (*C. aureus*).	Lesser Celandine (*R. ficaria*).	Mean.	Average, 7 Years, 1920-26.	Difference from Average.	Frog Spawn First Seen.
A (8) England SW. .	18	16	27	26	22	22	0	40
B (10) Ireland S. .	15	18	30	37	25	*20	+ 5	44
C (5) England SE. .	19	22	30	35	27	26	+ 1	57
D (4) England Mid. .	17	26	41	53	34	31	+ 3	68
E (3) England E. .	17	22	35	49	31	30	+ 1	75
F (7) England NW. .	22	27	43	53	36	33	+ 3	68
G (9) Ireland N. .	19	19	44	43	31	27	+ 4	51
H (6) Scotland W. .	28	26	49	68	43	*32	+11	67
I (2) England NE. .	29	33	52	65	45	37	+ 8	70
J (1) Scotland E. .	29	33	51	81	49	47	+ 2	82
K (0) Scotland N. .	(39)	38	64	77	55	*47	+ 8	61
Sub-Districts :—								
A (i) Channel Isles .	[21]	[6]	(26)	[7]	15	...	...	...
A (ii) Eng. SW. only .	17	14	26	25	21	...	...	40
A (iii) S. Wales . .	20	23	30	36	27	...	...	42
D (i) Eng. W. Mid. .	13	21	38	39	28	...	...	61
D (ii) Eng. E. Mid. .	19	25	38	56	35	...	...	64
D (iii) Eng. N. Mid. .	30	32	48	59	42	...	...	79
F (i) N. Wales . .	21	23	39	44	32	...	...	61
F (ii) Eng. NW. only .	22	29	45	56	38	...	...	74
H (i) Isle of Man .	...	16	[41]	32	...	...	...	[36]
Total Records Used	182	296	270	284	...	...	...	102
Mean of All . .	22.9	25.5	42.4	53.4	36.1	32.0	+4.1	62.1
Month and Day . .	J.23	J.25	F.11	F.22	F.5	F.1	...	Mr.2
Average 15 yrs. 1913-27	18.3	22.3	38.0	48.9	31.9	...	...	...
Month and Day . .	J.18	J.22	F.7	F.18	F.1	...	...	...

* Full 7-year period not available.

SUMMARY OF OBSERVERS' NOTES.

(References are to the districts and the 20-mile squares given in Fig. 1.)

An exceptional season has brought even fuller notes than 1926/7, particularly of birds. Many of these notes deal with the meteorological conditions discussed in our Summary.

In Winter.—A0e, frosts December 17-21 (18°F.) worst in 50 years, B50a, 3 feet of snow, March 12, then blighting wind and frost; birds too dazed to seek food. I38c, Lemmington, very late relatively to its area shown by last 3 seasons for the 14 plants and the migrants. Cause not traced. Many report record destruction by December frosts.

In Spring.—B27a, great set-back by 7 April frosts. Fruit promise destroyed. This very general. C11d, a trying spring, despite average records, specially the April set-back. E10b, frosts most hurtful, April 12-19, including laburnum, lilac, rose. H27e, June 4, 9°-12° frost, leaves of beech, ash, etc., seared, still black after weeks; fresh shoots and leaves from end August. K18b, harm by May-June drought.

Late Summer onwards.—C15g, farmers and all "grateful to Creator for sunny, beautiful summer." C21d, wonderful summer; dykes all dry, first time for years. D6b, mid-June to end September lovely. 17d, 28 days drought from July 9; splendid for crops with high

TABLE V.—MEAN DATES (DAY OF YEAR) FOR THE FLOWERING OF FOURTEEN PLANTS IN 1928 AND DIFFERENCE FROM THE AVERAGE OF THE 35 YEARS, 1891-1925.

PLANTS.	A (8) England, SW.			B (10) Ireland, S.			C (5) England, SE.			D (4) England, Mid.			E (3) England, E.			F (7) England, NW.		
	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.
1. Hazel (*Corylus avellana*)	37	38	− 1	34	33	+ 1	34	32	+ 2	43	41	+ 2	33	35	− 2	43	43	0
2. Coltsfoot (*Tussilago farfara*)	52	55	− 3	49	58	− 9	51	58	− 7	54	63	− 9	52	61	− 9	60	62	− 2
3. Wood Anemone (*Anemone nemorosa*)	84	84	0	72	77	− 5	75	82	− 7	86	89	− 3	81	88	− 7	87	90	− 3
4. Blackthorn (*Prunus spinosa*)	84	89	− 5	88	82	+ 6	87	94	− 7	98	99	− 1	92	96	− 4	104	102	+ 2
5. Garlic Hedge-Mustard (*Sisymbrium alliaria*)	106	107	− 1	111	112	− 1	106	110	− 4	111	113	− 2	109	111	− 2	115	122	− 7
6. Horse-Chestnut (*Æsculus hippocastanum*)	122	122	0	125	123	+ 2	121	126	− 5	129	130	− 1	123	126	− 3	129	132	− 3
7. Hawthorn (*Cratægus oxyacantha*)	123	130	− 7	130	131	− 1	122	130	− 8	128	133	− 5	125	131	− 6	132	138	− 6
8. White Ox-Eye (*Chrysanthemum leucanthemum*)	142	145	− 3	143	144	− 1	143	141	+ 2	152	149	+ 3	148	145	+ 3	150	154	− 4
9. Dog Rose (*Rosa canina*)	156	155	+ 1	160	158	+ 2	155	155	0	161	159	+ 2	156	155	+ 1	160	162	− 2
10. Black Knapweed (*Centaurea nigra*)	181	172	+ 9	193	184	+ 9	183	171	+12	185	177	+ 8	188	177	+11	196	189	+ 7
11. Harebell (*Campanula rotundifolia*)	196	193	+ 3	[195]	185	+10	197	186	+11	198	191	+ 7	194	189	+ 5	197	188	+ 9
12. Greater Bindweed (*Convolvulus sepium*)	194	186	+ 8	198	192	+ 6	192	187	+ 5	195	191	+ 4	190	190	0	200	196	+ 4
13. Devil's-Bit Scabious (*Scabiosa succisa*)‡	220	214	+ 6	216	215	+ 1	221	217	+ 4	223	215	+ 8	217	216	+ 1	216	219	− 3
14. Ivy (*Hedera helix*)	264	264	0	268	263	+ 5	274	260	+ 5	271	268	+ 3	275	266	+ 9	269	277	− 8
Mean of Plants 1-7	87	89	− 2	87	88	− 1	85	90	− 5	93	95	− 2	88	93	− 5	96	98	− 2
Mean of Plants 8-12	174	170	+ 4	178	173	+ 5	174	168	+ 6	178	173	+ 5	175	171	+ 4	181	178	+ 3
Mean of the 13 Plants (excluding Scabious)	134	134	0	136	134	+ 2	134	135	− 1	139	139	0	136	136	0	142	143	− 1
Mean of the 14 Plants (including Scabious)	140	140	0	142	140	+ 2	140	140	0	145	144	+ 1	142	142	0	147	148	− 1

	G (9) Ireland, N.			H (6) Scotland, W.			I (2) England, NE.			J (1) Scotland, E.			K (0) Scotland, N.			England and Wales.*			British Isles.†		
1. Hazel	44	48	− 4	54	49	+ 5	47	46	+ 1	56	55	+ 1	59	50	+ 9	39	39	0	44	44	0
2. Coltsfoot	59	67	− 8	64	67	− 3	61	64	− 3	75	73	+ 2	84	76	+ 8	55	60	− 5	60	64	− 4
3. Wood Anemone	87	88	− 1	96	97	− 1	92	93	− 1	101	104	− 3	105	107	− 2	84	88	− 4	88	91	− 3
4. Blackthorn	96	100	− 4	112	112	0	106	107	− 1	124	116	+ 8	114	115	− 1	95	98	− 3	100	101	− 1
5. Garlic Hedge-Mustard	107	112	− 5	122	127	− 5	115	121	− 6	132	128	+ 4	*128*	128	0	110	114	− 4	115	119	− 4
6. Horse-Chestnut	133	131	+ 2	135	142	− 7	140	138	+ 2	151	145	+ 6	153	142	+11	127	129	− 2	133	133	0
7. Hawthorn	136	138	− 2	138	145	− 7	139	139	0	151	148	+ 3	142	152	−10	128	133	− 5	133	139	− 6
8. White Ox-Eye	153	155	− 2	157	160	− 3	158	157	+ 1	169	164	+ 5	165	167	− 2	149	148	+ 1	153	154	− 1
9. Dog Rose	161	165	− 4	164	166	− 2	171	167	+ 4	178	169	+ 9	171	169	+ 2	160	159	+ 1	163	163	0
10. Black Knapweed	194	198	− 4	200	199	+ 1	199	192	+ 7	211	198	+13	[211]	204	+ 7	189	180	+ 9	195	190	+ 5
11. Harebell	193	196	− 3	199	194	+ 5	202	191	+11	208	195	+13	198	197	+ 1	197	189	+ 8	198	192	+ 6
12. Greater Bindweed	195	203	− 8	199	198	+ 1	202	198	+ 4	211	207	+ 4	[203]	202	+ 1	195	191	+ 4	198	198	0
13. Devil's-Bit Scabious‡	214	216	− 2	215	222	− 7	217	212	+ 5	217	207	+10	216	205	+11	219	216	+ 3	217	218	− 1
14. Ivy	275	277	− 2	283	277	+ 6	276	280	− 4	289	290	− 1	*293*	291	+ *2*	271	270	+ 1	276	276	0
Mean of Plants 1-7	95	98	− 3	103	106	− 3	100	101	− 1	113	110	+ 3	112	110	+ 2	91	94	− 3	96	99	− 3
Mean of Plants 8-12	179	183	− 4	184	183	+ 1	186	181	+ 5	195	187	+ 8	190	188	+ 2	178	173	+ 5	181	179	+ 2
Mean of the 13 Plants	141	144	− 3	148	149	− 1	147	146	+ 1	158	153	+ 5	156	154	+ 2	138	138	0	143	143½	− ½
Mean of the 14 Plants	146	150	− 4	153	154	− 1	152	150	+ 2	162	157	+ 5	160	157	+ 3	144	144	0	148	148½	− ½

* Average of Districts A, C, D, E, F, I. † The mean of the 13 and 14 plants for the British Isles is given to the nearest half-day.

‡ The averages for Scabious are based on the 7 years 1921-27 adjusted to the normal period by comparison with Greater Bindweed.

TABLE VI.—MEAN DATES OF FLOWERING, WITH THEIR VARIATIONS FROM THE 35 YEARS' AVERAGE (1891-1925), FOR THE THIRTEEN PLANTS IN THOSE DISTRICTS WHERE THERE HAVE BEEN SUFFICIENT OBSERVATIONS TO WARRANT COMPARISONS BEING MADE. ALSO, TOTAL NUMBER OF STATIONS IN ALL ELEVEN DISTRICTS.

Year.	No. of Stations.	A (8) Eng. SW.		C (5) Eng. SE.		D (4) Eng. Mid.		E (3) Eng. E.		F (7) Eng. NW.		H (6) Scot. W.		I (2) Eng. NE.		J (1) Scot. E.		Mean Difference from Average for the 8 Districts.
		Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	Day of Year.	Diff. from Average.	
†1891	105	144	+ 10	144	+ 9	150	+ 11	147	+ 11	150	+ 7	162	+ 13	157	+ 11	161	+ 8	+ 10.0
†1917	114	142	+ 8	141	+ 6	149	+ 10	145	+ 9	148	+ 5	153	+ 4	152	+ 6	160	+ 7	+ 6.9
‡1893	117	118	− 16	122	− 13	125	− 14	123	− 13	128	− 15	136	− 13	137	− 9	146	− 7	− 12.5
‡1921	205	125	− 9	120	− 15	127	− 12	125	− 11	133	− 10	149	0	130	− 16	145	− 8	− 10.1
1925	362	136	+ 2	134	− 1	138	− 1	135	− 1	143	0	143	− 6	144	− 2	156	+ 3	− 0 7
1926	373	129	− 5	129	− 6	134	− 5	130	− 6	137	− 6	142	− 7	142	− 4	148	− 5	− 5.5
1927	418	134	0	133	− 2	141	+ 2	136	0	142	− 1	147	− 2	144	− 2	156	+ 3	− 0.4
*1928	467	134	0	134	− 1	139	0	136	0	142	− 1	148	− 1	147	+ 1	158	+ 5	+ 0.4
Avge. 1891– 1925	...	134 My 14	...	135 My 15	...	139 My 19	...	136 My 16	...	143 My 23	...	149 My 29	...	146 My 26	...	153 Jn. 2	...	142 My 22

* Leap year. † Two latest years. ‡ Two earliest years.
The entire series, up to 1925, appears in the Report of that year.

day temperatures. Doubtful if ever better. 35a, unprecedented mushroom crop all October. 49c, dry July, hard on birds; young rooks gasping for breath. F32a (1,000 feet), wretched summer, frosts late and hard, some every month, 15° on October 1.

PROFUSE FLOWERING records were chiefly confined to fruit trees and dog rose, though D22a includes all flowering shrubs and hollyhock with 16 spikes, some 11 feet tall.

SECOND FLOWERING appears to have been less common than usual, except apple, laburnum and dog rose. B14a reports many spring flowers recurring in autumn, including lilac. D39e, ivy in early spring; and 21d, Christmas rose in June!

FRUITING was badly hit as a rule by the mid-April and May cold spells; different kinds, however, escaped at one place or another. So haws ("a feature of the landscape") and small fruits at A5b, damsons at 6e; yew berries, 15f; apples at D4d; acorns at 5d ("never seen more"), and 6a; damsons at H18d (missed April frosts), apples large and fine, I21b; 38a gives fruit lists, 12 kinds, good (above all, wild raspberries; so J19a), 21 poor and 14 nil or very scarce. J36a reports no wild fruits because of snow and frost on June 10, and few in garden; but J39b can rejoice in a good crop of excellent apples and pears.

CROPS.—Good reports come from nearly all parts as to quality, quantity and freedom from disease of potatoes, though no small frost damage occurred in June on low-lying land. Otherwise crop reports are diverse. B14b, the worst year all round, none over the average, poor and badly-saved hay, oats worst crop remembered, being late sown

(*Continued on page* 255.)

TABLE VII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST. MICHAEL'S, TENBURY, WORCESTERSHIRE, 1928, BY FREDERICK LOWE.

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.
1. Alder	*Alnus glutinosa*	69	101	123	271	300	313
2. Apple (Wild)	*Pyrus malus*	120	101	121	264	288	305
4. Ash (Common)	*Fraxinus excelsior.*	105	129	141	273	289	305
5. „ (Mountain)	*Pyrus aucuparia*	123	85	106	250	280	300
6. Acacia	*Robinia pseud-acacia*	167	129	163	262	299	305
7. Almond	*Amygdalus communis*	90	98	120	274	303	313
10. Barberry	*Berberis vulgaris*	127	96	107	260	301	313
11. Blackthorn	*Prunus spinosa*	99	101	110	254	279	305
12. Birch	*Betula alba*	119	101	115	239	276	305
13. Beech	*Fagus sylvatica*	129	117	123	245	294	314
16. Currant (Black)	*Ribes nigrum*	101	68	101	229	274	288
17. „ (Red)	*Ribes rubrum*	101	79	103	238	266	288
18. Chestnut (Horse)	*Æsculus hippocastanum*	127	96	115	259	276	305
19. „ (Spanish)	*Castanea vesca*	198	122	130	274	293	313
20. Cherry (Wild)	*Prunus avium*	96	97	109	250	280	300
21. „ (Bird)	*Prunus padus*	127	100	116	246	279	301
24. Cedar	*Cedrus libani*	281	99	139	...	...	...
25. Dogwood	*Cornus sanguinea*	171	104	122	241	287	305
27. Elm (Common)	*Ulmus campestris*	78	130	149	266	307	321
30. „ (Wych)	*Ulmus montana*	60	113	123	245	288	304
31. Elder	*Sambucus nigra*	150	46	97	245	274	304
32. Fir (Spruce)	*Abies excelsa*	106	119	129	...	...	...
33. „ (Scots)	*Pinus sylvestris*	127	142	157	...	...	...
37. Hazel	*Corylus avellana*	39	87	110	243	288	305
38. Hawthorn	*Cratægus oxyacantha*	124	60	96	250	280	305
39. Holly	*Ilex aquifolium*	123	122	155	...	...	...
41. Honeysuckle (Wild)	*Lonicera periclymenum*	162	38	85	252	299	325
42. Ivy	*Hedera helix*	263	106	129	...	...	...
47. Laburnum	*Cytisus laburnum*	126	96	115	245	299	313
52. Laurel (Common)	*Cerasus laurocerasus*	112	97	130	...	...	...
53. Larch	*Pinus larix*	85	79	100	260	299	314
54. Lilac	*Syringa vulgaris*	119	58	97	243	288	313
55. Lime	*Tilia europæa*	202	122	128	241	276	289
57. Maple (Field)	*Acer campestre*	122	105	121	251	280	300
58. „ (Norway)	*Acer platanoides*	106	116	128	245	276	289
59. Medlar	*Mespilus germanica*	137	69	100	275	288	300
60. Mezereon	*Daphne mezereum*	1	46	96	233	287	305
62. Oak (Acorns on stems)	*Quercus robur*	119	118	128	267	305	326
63. „ (Acorns sessile).	*Quercus sessiliflora*	118	118	127	260	300	321
65. Poplar (Grey)	*Populus canescens*	88	127	148	261	301	315
67. „ (Lombardy)	*Populus fastigiata*	69	99	117	252	289	307
69. Privet	*Ligustrum vulgare*	173	79	122	...	...	...
70. Pear (Common)	*Pyrus communis*	88	99	115	241	281	290
71. Plum (Common)	*Prunus domestica*	87	99	115	233	279	289
73. Quince	*Cydonia vulgaris*	127	68	99	273	295	306
74. Ribes	*Ribes floridum*	68	65	94	238	285	306
76. Raspberry	*Rubus idæus*	142	78	111	226	288	306
77. Rose (Guelder)	*Viburnum opulus*	151	88	122	241	288	306
78. „ (Field)	*Rosa arvensis*	167	51	97	225	273	306
79. „ (Dog)	*Rosa canina*	155	48	110	220	281	313
81. Snowberry	*Symphoricarpus racemosus*	155	69	96	252	295	313
82. Syringa	*Philadelphus coronarius*	157	69	97	245	274	305
83. Spindle	*Euonymus europæus*	146	98	112	241	288	305
84. Sycamore	*Acer pseudo-platanus*	118	100	118	253	288	300
86. Willow (Goat)	*Salix caprea*	71	97	115	252	288	317

TABLE VII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST. MICHAEL'S, TENBURY, WORCESTERSHIRE, 1928, BY FREDERICK LOWE—*continued.*

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.
87. Willow (Common) .	*Salix fragilis & viminalis*	116	96	115	251	288	11
88. „ (White) .	*Salix alba* . . .	116	103	115	260	289	320
89. Walnut . . .	*Juglans regia* . .	*	*	137	245	291	300
90. Yew . . .	*Taxus baccata* . .	50	107	129	...	...	..

* Walnut flower and first leaf frosted, second leaf May 1st (122). January, February and March were mild and open. On April 1st vegetation was not unduly advanced, however. There was good blossom on fruit trees but much damage was caused by frosts during April 17th-20th.

Autumn tints beginning to show, October 1st (275).
First heavy fall of leaf, October 19th (293).
Tints full on but patchy, October 26th (300).
Trees generally leafless, November 13th (318).

SEVEN SELECTED TREES.

AVERAGES, 1915-24.

Common Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.
13. Beech . .	133	113	125	227	289	313
18. Chestnut (Horse)	127	99	117	247	280	302
27. Elm (Common)	54	124	145	267	310	331
37. Hazel . .	30	103	125	236	288	314
38. Hawthorn .	126	78	107	239	286	305
57. Maple (Field)	133	120	132	249	283	306
84. Sycamore .	119	105	121	244	287	303
Mean of the 7 ...	103	106	125	244	289	311
Month and Day ...	Ap. 12	Ap. 15	My. 4	Ag. 31	Oc. 15	N. 6

DIFFERENCE OF 1928 FROM AVERAGE.

First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.
− 4	+ 4	− 2	+18	+ 5	+ 1
0	− 3	− 2	+12	− 4	+ 3
+24	+ 6	+ 4	− 1	− 3	0
+ 9	−16	−15	+ 7	0	− 9
− 2	−18	−11	+11	− 6	0
−11	−15	−11	+ 1	− 3	− 6
− 1	− 5	− 3	+ 9	+ 1	− 3
+ 2.1	− 6.7	− 5.7	+ 8.3	− 1.4	− 3.4

Mean of the 7.

TABLE VIII.—ADDITIONAL RECORDS OF PLANTS ON THE INTERNATIONAL LIST. (DATES OF FIRST FLOWERING UNLESS OTHERWISE STATED.)

BRITISH ISLES MEANS.	Christmas Rose (1927-8) (*Helleborus niger*).	Almond (*Amygdalus communis*).	Horse Chestnut Leafing.	Red Currant (*Ribes rubrum*).	Oak (Acorns on Stems) (*Quercus pedunculata*).	Purple Lilac (*Syringa vulgaris*).	Bird Cherry (*Prunus padus*).	Laburnum (*Cytisus laburnum*).	Elder (*Sambucus nigra*).	White Acacia (*Robinia pseud-acacia*).	Madonna Lily (*Lilium candidum*).	Autumn Crocus (*Colchicum autumnale*).	Horse Chestnut Fruit Ripe.	Horse Chestnut Colour Change	Horse Chestnut Leafless
Total Records Used	12	15	11	14	16	29	12	27	26	9	13	12	7	7	8
Mean, 1928 . Month and Day .	−8 Dec. 23	76 Mar. 16	101 Apr. 10	101 Apr. 10	121 Apr. 30	123 May 2	120 Apr. 29	129 May 8	149 May 28	177 Jun. 25	187 Jul. 5	241 Aug 28	265 Sep. 21	275 Oct. 1	306 Nov. 1

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928.

Song-Thrush (*Turdus musicus*) first heard; Swallow (*Hirundo rustica*) first seen; Cuckoo (*Cuculus canorus*) first heard; Nightingale (*Daulias luscinia*) first heard; Flycatcher (*Muscicapa grisola*) first seen; Swallow (*Hirundo rustica*) last seen; Honey-Bee (*Apis mellifica*); Wasp (*Vespa vulgaris*); Small White Butterfly (*Pieris rapae*); Orange-Tip Butterfly (*Anthocaris cardamines*); Meadow-Brown Butterfly (*Epinephile janira*); Humble Bee (*Bombus lapidarius*) first seen.

STATION.		BIRDS.						INSECTS.					
		Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey-Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
A.(i.)	Channel Isles : Guernsey,												
0a.	Les Blanches	8	111	108	108	...	302	...	...	97	...	164	113
0b.	St. Pierre	1	112	100	...	126	...	...	...	...	...	...	...
0d.	Les Hubits	7	104	105	...	...	...	54	...	97	...	172	*127*
	Jersey,												
0e.	Westmount	6	107	101	...	125	...	56	...	101	117	145	*55*
	A (ii) (8)												
1a/d.	Carbis Bay	8	92	117	...	...	296	...	...	95	...	...	...
1b.	St. Buryan	6	...	109	...	...	304	...	...	...	122	*122*	*60*
2f.	Phillack, Hayle	17	100	117	...	...	...	53	...	110	...	141	*144*
4b.	Lambourne Hill	*35*	104	113	...	...	309	51	97	119	121	...	99
5a/b.	Polperro	30	98	105	...	...	308	...	...	108	122	160	99
6a.	Duloe	11	103	118	...	...	293	53	...	...	120	151	*197*
6c.	Lopwell	15	104	111	...	134	287	50	92	99	103	160	107
8b.	Buckfastleigh	6	103	114	...	...	284	58	103	111	...	...	72
8e.	Plymstock	20	105	110	111	128	...	57	102	101	127	159	...
9a.	Launceston	9	103	112	...	...	278	50	...	118	127	...	...
9c.	Clawton	16	117	116	...	129	274	51	96	102	119	158	...
10b.	Torquay	13	112	117	...	...	...	18	*120*	115	122	...	122
10e.	Teignmouth	10	111	119	...	...	...	*70*	...	120	127	156	...
11d.	Copplestone	17	106	111	...	...	...	...	115	...	...	...	...
11e.	Lydford	13	115	111	...	...	276	...	...	...	...	...	...
11f.	Okehampton	11	103	*102	...	...	288	56	...	...	†103	*112*	86
11g.	Colebrooke	9	94	111	...	*105*	286	...	...	111	124	156	...
12b.	Bideford	...	98	112	...	128	...	...	...	...	...	...	...
12e.	Forda Moor	...	102	112	...	130	281	...	...	...	...	...	...
12f.	Kilkhampton	*43*	101	95	...	...	...	53	101	108	120	...	93
13a.	Exmouth	15	107	108	...	126	284	53	95	86	...	150	95
13c.	Exeter	*35*	97	*123*	126	*151*	269	...	...	97	116	...	109
14a.	Umberleigh	17	94	...	...	141	...	52	94	111	134	...	...
14b.	Bish'p's Tawton	2	96	104	...	...	282	53	87	84	103	*182*	...
14d.	Barnstaple	7	105	112	...	132	277	52	...	111	...	...	...
15a.	Buckerell	...	98	114	...	...	...	...	53	116	121	...	...
15c.	Lyme Regis	3	97	113	...	...	...	...	...	113	119	165	64
15d.	Sidford	10	105	107	...	...	280	...	110	...	...	...	...
17‡.	Combe Martin	1	105	93	...	...	...	*2*	54	93	...	*63*	64
18a.	Weymouth	5	100	104	...	128	...	40	116	99	...	...	93
19c.	Bradney	8	104	111	...	118	281	57	...	...	128	...	...
19f.	Staplegrove	2	110	109	113	*148*	...	51	99	105	122	...	93
20a.	West Porlock	2	95	108	...	135	...	61	...	...	...	...	...
21d.	Broadstone	17	107	107	...	...	275	24	*123*	*64*	...	*183*	...
21f.	West Moors	...	100	109	116	128	280	...	...	*122*	...	...	...

* Observed at N. Tawton, 7 m. E. † At Bridestowe, 7 m. W.
‡ Combination of the three stations, 17a, b, c.

TABLE IX.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects, 1928—*continued.*

STATION.	BIRDS.						INSECTS.					
	Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey-Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
24a. Pimperne .	...	101	104	108	132	276	...	...	...	...	...	...
25b/h. Flax Bourton	4	103	106	...	...	282	52	82	*53*	121	160	99
25c. Keynsham .	10	105	105	124	146	...	49	112	116	128	175	86
25f. Pensford . .	15	110	102	...	...	...	...	...	...	...	...	...
27c. Portishead .	8	101	102	119	...	280	52	100	116	121	156	98
28b. Clevedon .	7	98	108	119	...	277	64	...	112	...	108	...
A (iii.) (8)												
28c. Cardift .	6	106	116	...	141	280	60	...	116	131	153	...
28d. Llandaff .	19	103	108	...	...	†295	...	...	...	...	...	...
29a. Bridgend .	13	110	117	...	...	274	63	*123*	117	...	...	*77*
30a. Mumbles .	7	100	106	...	...	300	52	117	102	128	...	*118
32a. Tenby .	9	101	112	...	...	288	48	115	103	130	*133*	112
32c. Pembroke .	...	107	111	...	...	294	...	...	...	110	...	...
34c. Philadelphia .	29	98	98	...	...	302	*108*	*121*	116	113	*119*	117
34d. Carmarthen .	...	112	102	...	125	275	...	...	...	...	...	...
35a. Fishguard .	22	102	114	...	...	273	43	101	...	...	*104*	...
42a. Talgarth .	...	106	108	...	129	...	...	119	121	125	158	...
43a. Hafod . .	30	118	116	...	...	277	52	118	118	138	168	108
43c/d. Aberystwyth .	12	97	115	...	129	294	50	103	99	113	148	*51*
44a. New Radnor .	47	91	110	...	121	261	63	104	98	114	*141*	110
B (10).												
4a. Darrynane Abbey.	20	109	118	...	...	268	53	*139*	109	116	165	110
6a. Timoleague .	5	100	107	...	141	312	*122*	120	110	120	162	*65*
14a. Monkstown .	7	102	...	...	...	272	60	...	...	...	...	*123*
14b. Passage West	17	115	115	...	...	280	...	...	...	127	...	...
22b. Castle Lyons .	5	103	119	...	128	282	53	121	118	120	168	88
27a. Castleconnell .	14	100	119	...	126	280	99	96	119	119	163	*130*
27b. Corbally, Limerick .	4	‡96	119	...	117	§287	66	99	119	122	...	...
30a. Cashel . .	11	99	116	...	*151*	269	103	117	108	119	172	84
34b/f. Kilkenny .	3	101	116	...	...	281	*6*	110	113	120	119	97
34d. Freshford .	...	98	118	...	...	278	...	...	...	*149*	...	...
37b. Killinick .	13	105	112	...	...	300	93	...	...	...	...	110
38a/b. Borris .	16	98	111	...	137	*249*	58	93	120	120	132	*133*
42b. Rathvilly .	19	118	117	...	...	271	...	...	120	120	...	...
42d. Hacketstown .	...	113	119	...	...	280	93	...	...	121	150	...
43a. Mountmellick	16	98	118	...	*147*	273	57	...	103	116	...	*126*
43b. Stradbally .	16	104	117	...	...	294	...	...	...	...	*80*	...
50a. Johnstown Bridge .	*36*	109	119	...	...	266	*113*	121	...	...	*248*	112
51a. Delgany .	...	102	126	...	...	290	...	...	...	122	...	...
52a. Portmarnock .	19	113	123	...	127	293	...	...	*127*	127	...	*127*
C (5).												
1‖ Bournemouth.	4	104	104	...	145	297	...	98	99	...	...	98
1j. Southbourne .	4	102	100	118	146	307	54	123	119	125	176	...
1d. Totland Bay .	...	103	109	...	...	292	...	...	...	...	...	...
1b. Ringwood .	9	106	104	108	119	309	51	...	...	...	...	*59*
1c. Lymington .	39	102	109	113	...	*205*	58	117	109	125	175	125
1i. Appleslade .	18	105	106	*140*	140	274	...	119	119	127	182	...
2a. Mere . .	15	102	104	...	...	...	49	119	103	147	...	123

* Observed at Ilston Valley, 6 m. W. † At Ramsey, Pembroke. ‡ Observed at Killaloe, 20 m. N. § At Askeaton, 16 m. SW. ‖ Combination of the three stations, 1a, e, f.

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.	BIRDS.						INSECTS.					
	Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly	Meadow-Brown Butterfly.	Humble Bee.
3a. Shanklin	4	94	93	111	...	294	64	...	86	128	162	85
3e/f. Southsea	5	100	102	109	123	306	23	92	102	122	153	80
3g. Newport	3	102	111	121	...	301	54	121	86	124	...	96
4b. Sherfield English	19	99	100	101	118	294	17	51	100	119	150	119
4c. Stratford-sub-Castle	17	105	111	...	118	297	63	65	...	...	...	...
4d. Minstead	13	114	108	...	...	275	...	...	...	...	...	...
4e/g. Romsey.	12	99	100	101	118	...	53	103	...	...	...	121
5d. Bratton	17	97	103	...	...	290	58	...	...	127	175	86
5e. Steeple Ashton	16	98	111	...	128	297	59	119	...	126	...	...
6a. Havant	7	87	100	122	...	295	53	42	99	126	177	63
6c. Chichester	3	101	100	117	...	298	57	...	103	140	*145*	100
6d/e. Hayling Island	5	99	111	115	...	299	51	*39*	86	144	*149*	78
7a. Botley	14	100	100	99	126	275	30	120	110	121	181	127
7c. Hythe	21	107	101	115	...	282	68	95	101	125	*129*	95
7f. Sutton Scotney	9	93	101	120	142	282	53	113	...	145	...	64
7h. Winchester	8	99	102	...	144	...	34	...	93	124	...	...
8b. Marlborough	20	102	111	...	127	309	58	...	*126*	125	166	*174*
10c. Littlehampton	12	118	*86*	...	...	272	59	110	*66*	130	161	...
11b. Newton Valance	15	110	104	...	127	*248*	49	*32*	...	...	...	118
11d. Grayshott	9	...	102	116	...	...	49	86	115	119	...	86
11e. Chiddingfold	...	*124*	101	115	149	282	...	127	*126*	117	...	116
12b. Chilbolton	...	97	101	102	...	...	...	...	...	...	...	...
13a/b. Swindon	8	113	115	120	146	281	53	65	119	119	*186*	93
14a. Seaford	9	105	...	...	...	306	...	...	...	...	176	64
15e. Lower Beeding	12	99	98		130	270	...	117	116	118	176	...
15f. Cowfold	20	107	104	107	126	296	49	...	...	...	...	115
15g. Hassocks	15	103	101	117	127	280	51	*137*	116	126	172	122
16b. Farnham	14	114	104	...	...	290	...	...	...	128	...	...
16f. Odiham	22	100	99	116	143	...	30	101	116	127	...	*132*
16g. Rowledge	11	115	*79*	117	...	...	50	49	102	131	...	*133*
16i. Churt	25	*123*	102	117	...	...	78	109	111	126	174	...
16m. Godalming	4	108	99	118	...	278	52	121	...	...	...	*50*
16n. Normandy, Guildford	40	118	102	114	...	...	49	...	119	136	...	...
18a. Lewes	7	97	102	112	129	*323*	50	117	99	119	175	...
18b/g. Hellingly	9	101	102	112	...	297	57	55	111	...	*148*	63
18c. Ditchling	4	109	105	120	122	298	70	93	80	137	170	81
18e. Waldron	58	101	101	115	*164*	...	31	124	...	...	...	86
19d. Sutton	8	116	117	121	141	*320*	62	94	113	146	*118*	...
20a. Reading	9	108	104	...	...	...	50	116	86	125	172	102
20c. Maidenhead	...	103	102	117	...	...	...	...	...	...	...	...
21b. Hastings	...	98	112	101	118	...	...	...	...	...	...	...
21c. Burwash	21	...	97	118	...	...	57	63	...	*101*	...	...
21d. Rye	18	102	112	...	132	305	57	90	99	119	167	90
22a. Lingfield	11	112	104	120	146	274	...	...	108	119	174	*53*
22b. Warlingham	3	98	110	110	...	...	59	...	100	118	164	*57*
22c. Purley	7	112	101	...	...	...	50	120	117	...	194	63
24b. Woodchurch	*58*	100	102	102	...	307	...	...	101	117	165	117

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.		BIRDS.						INSECTS.					
		Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey-Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
25a.	Maidstone .	16	115	101	120	...	...	...	...	*71*	*84*	...	...
25e.	Lenham .	24	*122*	*92*	...	...	275	65	102	117	141	...	*137*
25f.	Sutton Valence	...	104	103	120	...	...	...	...	...	...	...	...
25g.	Bearsted .	14	114	114	...	...	287	*115*	...	115	125	158	81
26d.	Sydenham .	11	112	117	...	...	...	58	*134*	100	...	...	...
27a.	Whitstable .	17	112	98	110	...	279	52	128	119	...	...	63
29a.	Ash, Sandwich	...	115	114	117	117	278	49	62	...	125	*127*	125
	D (i.) (4).												
1c.	Wotton under Edge .	14	112	112	...	...	274	52	...	116	126	...	129
3b.	Ross .	11	111	119	...	146	...	...	...	...	...	...	...
3d.	Longhope .	...	96	101	...	110	...	...	...	...	117	...	...
4a.	Weobley .	6	111	102	...	...	283	64	62	102	120	*118*	117
4d.	Staunton-on-Arrow	17	112	109	...	147	283	...	64	117	120	155	117
5d.	Coaley .	22	104	102	123	132	275	64	116	115	122	151	94
5e.	Churchdown .	10	102	107	116	130	...	...	95	...	117	...	...
5f.	Cheltenham .	7	95	112	...	128	293	52	121	117	127	176	101
6a.	Dymock .	22	103	103	...	136	...	51	116	95	125	...	128
6b.	Bromyard .	30	117	112	...	...	276	50	...	...	...	...	79
6c.	Kimbolton .	...	111	112	...	...	275	58	97	115	115	175	...
6d.	Colwall . .	18	...	...	...	...	...	51	50	...	122	...	...
9b/d	Bourton-on-the-Water .	7	105	111	...	134	301	50	64	116	119	172	84
10b.	Evesham .	3	115	116	...	147	...	...	86	116	...	...	111
10d.	Offenham .	17	111	103	114	135	...	54	121	*64*	*64*	*64*	126
10e.	West Malvern	36	97	108	...	...	298	...	94	117	...	160	*200*
11a.	Tenbury .	1	101	108	134	136	280	50	50	117	117	*194*	129
16b.	Cookley, Wolverley .	14	107	112	...	147	288	...	58	115	...	...	...
16c.	Barnt Green .	...	106	...	...	145	...	50	64	117	131	...	*131*
16f.	Frankley .	22	95	112	...	...	270	94	64	114	118	...	99
17b.	Newport .	...	101	116	...	146	279	...	...	...	...	...	...
17c.	Uffington .	...	101	112	*104*	120	281	...	...	121	125	183	...
17d.	Benthall .	...	...	...	...	...	288	...	...	101	134	163	...
23a.	Wem . .	...	108	119	...	...	288	...	...	...	...	...	...
	D (ii.) (4)												
8a.	Goring . .	...	109	113	...	...	302	...	...	...	...	...	...
10c.	Ashorne .	46	105	107	114	128	283	65	...	117	...	...	...
13b.	Gerrard's Cross	47	105	103	...	...	...	...	...	...	...	...	*50*
13c.	Chalfont St. Peter		*126*	103	...	...	274	...	119	115	126	176	...
13d.	Beaconsfield .	8	112	109	119	...	...	50	120	111	119	...	...
14a/b.	Oxford .	22	97	106	122	...	274	52	118	100	118	...	82
15a.	Whernalls .	14	...	108	116	...	...	...	...	...	...	...	64
15c.	Stratford-on-Avon	3	103	102	116	141	270	...	...	115	125	163	...
15d.	Pillerton Hersey	26	102	113	119	...	284	49	119	...	...	...	...
19b.	Granborough .	23	112	117	...	122	304	50	65	...	117	175	86
20a.	Farnborough .	9	110	113	...	125	*257*	...	127	117	124	176	120

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.	BIRDS.						INSECTS.					
	Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
21h. Blackdown .	25	104	116	116	147	274	64	103	117	126	153	116
21i. Yardley Wood	31	*125*	93	...	...	267	63	134	...	139	*116*	90
24a. Bletchley .	1	101	102	117	...	...	...	...	107	122	153	...
24b. Northampton .	21	103	112	...	...	279	50	120	...	...	...	64
26b. Sutton Coldfield .	5	108	121	...	146	270	*125*	...	117	*156*	...	...
28a. Little Harrowden .	21	100	101	116	121	271	56	102	116	127	*191*	*40*
29b. Loughborough	...	112	119	...	146	...	...	...	...	...	...	...
33a. Ketton . .	...	116	116	123	...	...	50	120	115	136	...	...
34a. Kegworth .	3	107	116	...	141	291	46	102	103	133	168	...
37c. Staunton .	4	113	111	...	...	...	...	...	...	125	...	...
38a. Hodsock .	1	100	114	...	...	273	...	50	125	...	...	86
38b. Mansfield .	7	112	*64*	115	122	287	50	49	107	...	...	102
D (iii.) 4												
35a. Somershal Herbert .	23	107	115	...	122	...	68	48	115	145	145	...
39a. Huddersfield .	47	117	119	...	...	274	...	...	126	...	...	117
39b. Kirkheaton .	*52*	120	122	...	...	274	...	...	120	...	...	...
39c. Thurlstone .	22	...	122	*152*	...	...	106	*155*	150	...	...	...
39d. Sheffield .	7	115	116	...	...	289	...	63	126	...	...	...
41a. Crosshills .	1	98	117	...	111	...	...	127	127	...	...	...
44a. Sitwell Vale .	10	*150*	121	...	...	267	85	...	*145*	...	...	97
44b. Newhill, Wath	34	115	117	...	...	267	60	...	118	...	...	...
44f. Ackworth .	43	102	117	...	143	290	...	126	125	*154*	*193*	...
45a. Overton .	36	107	105	...	...	269	...	126	127	...	...	...
49c. Bolton Percy.	31	106	122	...	...	...	...	...	120	...	*194*	...
49d. Kirk Deighton	34	111	102	...	...	...	39	104	*43*	...	...	113
E (3)												
1*. Barnet . .	6	111	99	...	...	274	56	...	113	126	...	60
2e. Aldbury .	11	106	98	111	123	301	62	125	*59*	124	*130*	111
3a. S. Woodford .	*45*	114	116	116	...	264	...	...	...	...	...	...
3c. Enfield . .	26	104	110	...	...	...	49	...	...	...	...	...
3d. Warley . .	11	98	111	115	...	279	56	...	102	124	155	...
4b. Knebworth .	24	109	103	...	...	284	50	49	*79*	...	...	80
4i. Hitchin . .	13	97	101	100	135	...	59	...	86	127	173	80
4k. Pirton . .	...	100	114	122	...	...	50	64	99	116	155	91
4m. Luton . .	11	104	113	116	...	284	...	...	...	120	...	...
5a. Turvey . .	11	99	102	116	135	300	50	116	102	126	166	100
7a. Birch Green .	10	99	97	121	132	308	42	53	106	114	...	*43*
7b. Sawbridgworth	7	99	108	...	123	297	49	108	115	124	175	63
8a/b. Letchworth .	5	97	101	100	135	288	20	85	86	124	169	57
8e/f. Kempston .	1	107	110	119	130	292	29	101	101	124	161	96
10b. Halstead .	23	115	102	...	...	276	56	124	*127*	...	...	95
10f. Great Totham	14	103	103	100	113	292	49	79	98	126	165	64
10g. Pleshey .	...	106	108	...	...	...	50	...	85	124	181	77
11d/f. Cambridge .	7	98	100	117	135	297	49	120	119	*151*	...	*53*
12a. Keysoe . .	14	99	114	119	...	284	50	...	111	124	155	...
13a. Lexden . .	14	95	103	103	*150*	286	50	99	101	123	183	...

* Combination of the four stations 1b, c, d, f.

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.		BIRDS.						INSECTS.					
		Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
13c.	Frinton	...	99	119	101	...	...	...	...	...	...	...	...
14a.	Ballingdon	15	99	113	115	...	283	...	101	...	124	...	79
14d.	Denston	28	117	112	113	...	...	49	101	115	119	...	116
17b.	Ipswich	8	118	103	111	...	298	56	117	117	148	148	86
17e.	Boxford	15	100	116	116	143	...	50	101	115	124	...	120
17f.	Finborough	...	116	112	116	...	...	...	...	...	128	...	...
22b.	Langford	14	103	104	110	...	286	52	117	102	127	177	*146*
22d.	Grimston, Lynn	5	101	101	126	...	302	62	103	103	...	159	85
24b.	Postwick	28	104	105	...	127	300	47	*155*	111	126	*119*	88
24c.	Runhall	*44*	110	105	...	...	269	50	...	...	144	160	*170*
25a.	Hunstanton	...	98	114	...	...	282	50	...	102	...	149	63
26a.	Hemsby	2	100	103	118	132	261	57	117	...	...	...	117
26b.	Thurton	18	114	103	...	...	284	...	*9*	110	...	...	99
26c.	Blofield	...	102	101	...	133	...	...	119	108	124	...	...
27a.	Hevingham	16	111	116	...	...	...	...	...	...	...	..	...
27b.	Holt	...	97	113	...	124	299	...	94	90	*153*	168	...
	F (i.) (7)												
2‡.	Aberdovey	12	96	117	...	120	276	57	109	111	...	*183*	86
5a.	Ffestiniog	...	114	112	...	...	263	...	...	126	...	...	...
9a.	Beaumaris	14	101	117	...	...	289	63	117	118	*122	...	*134*
9b.	Deganwy	7	108	106	...	*148*	290	...	...	...	...	...	...
9d.	Trefriw	21	103	118	...	...	...	*119*	128	117	126	...	...
11d.	Trefnant	20	†112	†114	...	...	299	...	...	...	...	...	...
11h.	Abergele	3	110	111	...	134	264	*32*	111	*153*	153	162	92
13e.	Flint Mountain	20	111	113	...	...	270	111	113	118	*111*	*97*	101
13f.	Caerestyn	20	122	103	...	...	278	59	...	...	162	...	*172*
	F (ii.) (7)												
13c.	Hr. Tranmere	3	113	116	...	...	...	84	...	117	...	...	107
13d.	Shotwick	19	106	113	...	*145*	285	80	74	122	...	...	...
14a.	Barnton	19	100	113	...	127	275	*106*	118	119	131	162	97
14b.	Altrincham	6	113	111	...	133	275	63	*64*	106	...	...	...
16b.	Bramhall	4	102	111	...	136	297	52	105	105	...	...	114
16c.	Cheadle Hulme	...	104	115	...	127	285	...	...	...	...	...	...
16d.	Alderley Edge	8	113	...	...	142	278	78	103	117	...	...	...
16e.	Prestbury	20	102	120	...	141	288	64	...	...	...	...	...
18a.	Blackpool	35	102	*134*	...	...	267	...	...	...	...	...	100
18b.	Marton Mere	11	109	103	...	131	...	42	96	99	...	162	...
20a.	Nelson	...	111	122	...	134	284	64	101	111	127	164	...
21a.	Leyland	1	116	113	...	...	289	...	...	...	...	...	...
21c.	Mitton	22	116	118	...	120	273	...	...	127	...	...	108
22a.	Urswick	*44*	98	117	...	...	274	53	*146*	97	‖127	151	...
22b.	Ulverston	7	§100	117	...	...	274	...	...	...	...	...	...
22d.	Grange-over-Sands	...	113	117	...	129	...	49	116	98	122	162	...
24a.	Arnside	8	98	116	...	...	280	...	...	...	...	...	...
25a/b.	Ambleside	19	108	116	...	126	326	52	122	120	126	...	118
27a.	Kendal	12	116	...	...	...	260	52	120	121	129	158	*131*
28a/d.	Keswick	22	102	117	...	...	...	...	121	118	...	...	118
28b.	Johnby Hall	53	116	134	...	...	263	57	152	*152*	...	...	...

* Observed at Portmadoc. † At 10 m. SW. ‡ Combination of the three stations 2a, c, d. ‖ Observed 6 m. NW. § At Coniston, 13 m. N.

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.		BIRDS.						INSECTS.					
		Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
31b.	Carlisle .	14	105	113	...	133	277	...	...	...	...	...	...
32a.	Alston . .	40	117	118	...	150	293	...	145	125	164	...	...
	G (9)												
2a.	Loughrea .	*39*	*138*	119	...	...	259	83	111	118	140	151	...
11a.	Clogher .	16	106	111	...	...	273	...	...	99	117	...	...
18a.	Farragh .	17	106	116	...	...	268	61	99	119	126	...	...
35c/e.	Warrenpoint .	13	92	114	...	122	284	86	120	94	109	*184*	85
41c.	Scarva . .	12	105	105	...	...	...	68	...	...	...	...	86
45a.	Saintfield .	35	115	116	...	...	263	87	120	119	...	...	95
47a.	Sixtowns .	24	109	116	...	...	267	...	125	126	...	...	...
50c.	Belfast . .	3	100	120	...	...	278	43	...	...	...	...	...
50d.	Muckamore .	17	108	116	...	...	267	...	...	...	...	...	...
50f.	Woodbourne .	13	99	114	...	...	...	97	111	113	...	153	99
50g.	Comber .	14	115	117	...	...	284	90	...	98	...	*120*	102
51a.	Magherafelt .	16	117	122	...	...	270	93	124	*141*	142	155	*156*
54a.	Hazelbank .	5	107	114	...	140	273	69	100	100	130	162	108
54b.	Larne . .	...	112	113	...	...	274	75	119	...	...	...	...
55b.	Ballymoney .	*38*	116	119	...	...	272	79	...	120	*160*	172	107
H (i.)	(6) Isle of Man,*												
0a.	Baldrine .	13	102	118	...	128	318	...	...	...	...	...	...
0b.	Castletown .	16	98	...	...	...	313	...	...	...	...	...	...
0c.	Lezayre .	22	114	118	...	...	...	...	118	...	...	...	...
0d.	Peel .	29	98	113	...	...	274	57	...	103	...	...	127
0e.	Port St. Mary.	28	100	...	...	...	295	...	...	...	...	...	...
	H (ii.) (6).												
1a.	Drummore .	15	105	111	...	133	275	58	100	107	129	162	...
2a.	Marks . .	20	113	115	...	...	277	50	124	...	...	...	113
11a.	Collin .	7	115	115	...	*173*	257	*101*	120	118	*201*	*192*	*246*
12a.	Moniave .	...	116	116	...	...	280	...	...	127	...	...	...
18a.	Dumfries .	...	108	113	...	129	†306	...	115	122	...	...	...
18b.	Lockerbie .	*66*	122	115	...	127	...	59	120	123	...	...	149
18c.	Closeburn .	...	...	124	...	...	...	...	122	113	...	...	117
18d.	Keir Mill .	...	109	117	...	141	285	...	...	114	122	...	129
20b	Hareshawmuir	...	102	115	...	146	...	...	...	...	...	...	...
21a.	Ardnadam .	43	99	115	...	...	260	65	*91*	125	...	...	126
23a.	Armagour, Coll	...	112	120	...	...	...	86	...	111	140	147	157
27d.	Carluke .	27	117	119	...	...	265	50	126	119	...	*210*	157
27f.	Glasgow .	...	102	111	...	120	...	...	...	...	...	...	...
30a.	Cairndow .	25	113	116	...	...	274	80	117	122	*155*	172	152
33c.	Ledaig . .	32	117	116	...	129	270	63	...	119	...	...	161
	I (2).												
6a.	Lincoln . .	7	105	115	‡123	131	285	62	93	111	139	‖155	82
6b.	Kexby. .	22	112	110	120	137	276	64	122	116	137	170	...
8a.	Woodhall Spa	...	115	117	130	147	268	...	...	*118*	126	...	*127*

* Not included in the means of District H. † Observed at Ruthwell 8 m. SE.
‡ Observed at Stapleford, 10 m. SW. ‖ At Wrangle, 30 m. SE.

TABLE IX.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1928—*continued.*

STATION.		BIRDS.						INSECTS.					
		Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey-Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
9a.	Ashby	15	113	113	113	*157*	302	...	...	117	...	...	...
9b.	E. Stockwith	20	115	113	...	...	...	...	*145*	*150*	...	...	120
10a.	West Keal	23	...	117	...	146	275	...	...	...	...	...	*135*
11c.	New Waltham	8	113	104	...	...	288	64	...	...	...	...	84
11e.	Holton-le-Moor	13	105	115	...	128	...	...	...	101	128	151	100
11f.	Limber	9	113	117	...	134	...	38	123	118	...	*184*	...
12a.	Holderness	15	102	110	...	*116*	280	36	126	...	...	...	...
14a.	York	18	99	106	...	...	...	...	...	...	...	...	...
18a.	Middleton-in-Teesdale	42	111	117	...	129	270	49	...	...	...	*113*	...
20a.	Louth	...	97	103	...	...	288	...	*84*	...	...	...	...
21a.	Hull	10	109	112	...	...	290	*79*	119	111	138	168	100
21b.	Skidby	31	113	116	...	...	294	52	*134*	100	*94*	...	...
23a.	Thirsk	13	101	115	..	...	...	49	...	126	*156*	...	...
24b.	Darlington	21	103	116	...	...	306	59	94	116	131	*189*	...
26a.	Catcleugh	14	115	113	...	127	302	...	115	124	...	212	...
33a.	Lanchester	40	114	118	...	...	278	64	...	117	...	...	*154*
33b.	Chopwell	39	117	117	...	129	284	53	112	101	...	169	113
36a.	Seaton Delaval	*47*	123	118	...	...	263	...	...	111	...	153	...
38b.	Waren	39	99	117	...	...	291	43	126	...	...	...	*52*
38c.	Lemmington	31	111	114	...	139	298	50	117	131	148	194	101
38d.	Little Mill	19	97	128	...	131	...	52	123	133	...	192	105
	J (1).												
2a.	Broughton	34	116	116	...	132	296	52	126	126	...	...	...
4a.	Selkirk	7	105	117	...	*119*	300	...	...	...	...	...	...
6b.	Jedburgh	41	117	116	...	...	...	51	...	...	...	...	...
13a.	Stirling	17	114	128	...	137	268	53	123	..	...	...	...
13c.	Gargunnock	42	110	...	...	...	261	48	132	133	...	...	*145*
19a.	Milnathort	44	126	117	...	...	276	...	...	...	...	...	...
20a.	Loch Tummel	50	105	119	...	146	282	...	...	143	...	...	*142*
21b.	Tayport	13	121	...	...	...	276	...	...	...	...	...	...
36a.	Cabrach	51	131	118	...	149	264	85	115	115	131	160	118
36c.	Keith	...	125	125	...	...	258	50	128	...	...	...	135
39a.	Dunlugas	44	120	123	...	139	274	*101*	*153*	*162*	167	161	101
39b.	Forglen	44	123	111	...	...	276	46	123	*166*	...	159	116
40a.	Cullen	36	131	...	...	...	...	50	127	...	...	...	112
	K (0).												
18a.	Loch Carron	...	124	115	...	...	...	53	122	...	...	...	...
18b.	Stromeferry	...	118	116	...	...	282	...	...	...	...	...	...
18c.	Shieldaig	...	...	121	...	...	...	...	...	112	...	157	112
24b/c.	Muir of Ord	42	108	118	...	137	284	58	*169*	122	...	...	...
24d.	Kiltarlity	50	117	119	...	...	...	...	126	...	...	...	*141*
24e.	Beauly	...	120	117	...	146	...	...	...	...	...	...	...
26a.	Aviemore	56	105	117	...	...	...	50	...	...	...	...	...
27b.	Kirkhill	16	119	126	...	...	244	51	...	...	...	...	*50*
33a.	Golspie	28	120	126	...	...	...	...	...	...	...	...	131
43b.	Finstown, Orknev	19	...	122	...	...	...	...	...	...	...	...	

TABLE IX.—Date (Day of Year) of Song and Migration of Birds and First Appearance of Insects, 1928—*continued.*

STATION.	BIRDS.						INSECTS.					
	Song Thrush First Heard.	Swallow First Seen.	Cuckoo First Heard.	Nightingale First Heard.	Flycatcher First Seen.	Swallow Last Seen.	Honey-Bee At Flowers.	Queen Wasp On Wing.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
otal Records used	298	432	442	106	149	258	225	195	241	186	121	163
Sub-District Means.												
(i) Channel Isles	5	105	103	[108]	(125)	[302]	(55)	...	98	[117]	160	[113]
(ii) Eng. SW. only	10	104	110	117	132	284	50	93	107	120	158	93
(iii) S. Wales	18	103	111	...	129	285	54	111	109	122	156	107
(i) Eng. W. Mid.	15	106	110	122	136	284	57	83	113	122	167	108
(ii) Eng E. Mid	17	107	110	118	133	280	56	104	112	125	164	89
(iii) Eng. N. Mid.	28	110	117	...	125	275	72	95	123	[145]	[145]	111
(i) N. Wales	15	110	110	...	(127)	279	69	116	117	141	[162]	97
(ii) Eng. NW. only	18	109	116	...	132	283	60	114	114	134	160	109
I (i) Isle of Man	22	105	119	...	[128]	300	[57]	[118]	[103]	...	...	[127]
[27f. Av. 20 years*	...	100	113	...	130	...	...	...	...	...	...	...

* Average of observations made in the Clyde Valley, near Glasgow, during 20 years, 1908-27.

(*Continued from page* 244.)

and cut unripe at end of sunless August, potatoes rotted before ripe. But at 50a, grain and roots well up to average (no wheat grown). C7f, best wheat for 7 years. Quantities of poppies, after none for 5 years, though in 1922 many hundred acres; reason unknown. 15g, the "gloriously golden wheat a sight to gladden the eye." 22a, all good, except winter wheat injured by December frost. D3d, "bumper" hay and corn crops; yet 5a, oats, beans, vetches fail; garden crops none very good or very poor; damage by hail, slugs, blight. 49c, turnips poor from dry summer. F20, hay particularly good, but corn crops only average because of July drought. Again in Ireland, G11a, uneven quality and quantity of potatoes. 47a, hay and oats 14 days late, much hay spoilt; September 3-10, "awful." H30a, adverse effects of May dry east winds, then rain and severe cold. I24b, seeding time poor, first sodden, then too dry; hay crop short but excellent quality. 33b, excellent season for allotments. 33f, cereals excellent and ripened quickly. 36a, good for farm and garden. J36a (1,260 feet), good corn crop, cut immature, ingathered in fine condition, turnips splendid. 39b, grain crops light from lack of sun. Taken altogether, a much more cheerful report than in 1927.

General Bird Notes.—Aoa, thanks to English cold snap at mid-April, nightingales and other migrants numerous. Aoe, so too, thanks to French frosts in December and January, large flocks of missel thrushes. A1b, cuckoo, October 1. 12e, male hen harrier; birds nesting in garden week late, 62 kinds, out of 97 seen, nesting, 28 in 7-acre garden (land birds); authentic record of marsh warbler breeding. 14a, woodcock very early, one shot October 17. 18a, 2 chiffchaffs, November 9. 21f, thrushes singing whole year, least in September and October.

(Numerous records are made of early and full autumn song of thrush). [B34b reports hearing cuckoo in Trans-Jordan; told unusual]. B38b, young male black redstart, November 29. C1j, cuckoo very early (full notes on his migrants; so 1i). 2a, cuckoo sang more in June, as May so cold. 3f, swallow earliest ever seen; nightingale caught and ringed April 18, though no song till 25th, thanks to cold, several pairs of woodcock breeding within 5 miles of Portsmouth. 4b, good partridge year; flycatchers kill many bumble bees. 7c, thanks to cold and wet no full song of nightingale. So, 7h, no flycatchers till May 23, then many; so, too, at Cardridge, 7 miles S. of Winchester. 8b, list when migrant nests first seen. 11e, Dartford warbler. 15f, motor lights scaring away nightjars. 15g, snipe, October 30; woodcock, November 7. D5f, early blackbird song because of wild (and so mild) weather. 16b, April 4, house and sand martins thick round sewer effluence and no others. 21h, during December cold, big flocks of fieldfares and redwings on haws in garden. 49c, July drought hard on birds, several still nesting in August (yellowhammer, linnet, etc.). E1d, April 8, earliest cuckoo in 6 years. 8f, chiffchaff, March 26, earliest can recall. 17e, 8 great-crested wrens. 27b, snow buntings very early, September 26; flocks by mid-October, with other winter migrants, due to cold spell; storms end September, dispersed inland but not shore birds. F2a, blackcap pair wintered. 9b, snow bunting, November 1. 13f, most migrants late, due to wet, wild spring. 16e, blue-headed wagtail with yellow wagtails, rare, April 22. 18b, migrant groups small. 22a, an exhausted corncrake April 8; none heard till May 10. 22b, migrant inrush April 26-29, calling through the nights; redwings by night October 27, redwing flocks 40 to 100 each all day. 25a, swallow date latest known. Why? Swifts only earlier in 1916; and willow warbler in 1926. 25d, bird scarcity in garden in 1926/7 winter; reversed in '27/8; especially tits. 32a, migrants few and irregular, very few reared. G35c, 2 white wagtails, March 25; fieldfares by hundreds, October 30. 50g, male bullfinch, rare here (too much the reverse at C22c!). 55b, migrant arrivals not remembered so regular; pied blackbird on nest, one of several seen; autumn migrants early; mute swans passing inland from L. Neagh. G50c, after many years close observing concludes swifts leave nightly from August 10 to 15, for trial flights, returning at night, for none seen by day. Then final flight on August 18. Have others noted this? Hoa, return migration a week early. ob, first great northern diver. oe, cuckoo still, September 19, 23 miles N. of Pt. St. Mary. I11c, migration ceased April 13-22 from abnormal wintriness; so bramblings first on 29th; fieldfares still May 10. 12a, migrants to date but irregular; spotted flycatcher very early; nesting late. 14a, surprising owl increase, mainly barn, tawny, long-eared; little owl spreading. 24b, nesting good, except from June floods for ground birds, as grouse. J19a, all migrants late; coot nests drowned out. 36a, cuckoo early, silent from weather; fieldfare flocks very large, though few rowan berries. 40b, migrant decrease, some never came; redwings, June 14, perhaps domiciled, as in Ross-shire now quite often, first in 1926; large flock crossbills at Garvie. Siskins nest there. K18b, big fieldfare flocks, November 6, but went with cold and frost. 33a, constant fieldfare stream southwards 7 a.m. to 11 a.m., October 25. 43a (Orkneys) fewer fieldfares, no redwings by November 19; flocks of "snowflakes," November 6. 43b, autumn

(*Continued on page* 266.)

TABLE X.—MEAN DATES (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS IN 1928, AND DIFFERENCE FROM THE AVERAGE OF THE 35 YEARS, 1891-1925.

BIRDS AND INSECTS.	A (8) England, S.W.			B (10) Ireland, S.			C (5) England, S.E.			D (4) England, Mid.			E (3) England, E.			F (7) England, N.W.		
	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.	1928.	Average 35 years.	Difference from Average.
1. Song Thrush First Heard - - -	12	15	− 3	12	12	0	14	14	0	19	19	0	13	16	− 3	17	24	− 7
2. Swallow First Seen - - - -	103	105	− 2	105	105	0	104	105	− 1	107	109	− 2	105	109	− 4	108	110	− 2
3. Cuckoo First Heard - - - -	110	111	− 1	117	116	+ 1	105	107	− 2	112	112	0	108	111	− 3	114	117	− 3
4. Nightingale First Heard - - -	116	120	− 4	...	...	...	114	112	+ 2	119	117	+ 2	113	114	− 1	...	122	...
5. Spotted Flycatcher First Seen -	130	134	− 4	129	135	− 6	131	132	− 1	134	135	− 1	130	135	− 5	131	131	0
6. Swallow Last Seen - - - -	284	282	+ 2	282	279	+ 3	290	292	− 2	281	282	− 1	287	289	− 2	281	279	+ 2
Mean of Nos. 2, 3 and 5 - - -	114	117	− 3	117	119	− 2	113	115	− 2	118	119	− 1	114	118	− 4	118	119	− 1
7. Honey Bee at Flowers - - - -	51	58	− 7	73	61	+12	52	56	− 4	58	59	− 1	50	53	− 3	63	65	− 2
8. Queen Wasp on Wing - - - -	99	96	+ 3	110	99	+11	99	94	+ 5	93	101	− 8	100	94	+ 6	115	105	+10
9. Small White Butterfly - - - -	108	102	+ 6	114	108	+ 6	105	103	+ 2	115	112	+ 3	104	107	− 3	115	114	+ 1
10. Orange-Tip Butterfly - - - -	121	127	− 6	121	121	0	127	127	0	124	133	− 9	126	132	− 6	136	136	0
11. Meadow Brown Butterfly - - -	158	160	− 2	159	146	+13	171	164	+ 7	164	167	− 3	165	167	− 2	160	170	−10
12. Humble Bee - - - - - -	96	...	...	100	...	...	96	...	...	101	...	...	88	...	...	103	...	...
Mean of Nos. 7-11 - - - - -	107	109	− 2	115	107	+ 8	111	109	+ 2	111	114	− 3	109	111	− 2	118	118	0

BIRDS AND INSECTS.	G (9) Ireland, N.			H (6) Scotland, W.			I (2) England, NE.			J (1) Scotland, E.			K (0) Scotland, N.			England and Wales.*			British Isles.†		
1. Song Thrush - -	16	20	− 4	24	29	− 5	21	30	− 9	35	28	+ 7	35	41	− 6	16	19	− 3	20	23	− 3
2. Swallow First Seen -	107	108	− 1	111	113	− 2	109	114	− 5	118	118	0	118	126	− 8	106	109	− 3	109	111	− 2
3. Cuckoo - - -	115	118	− 3	116	120	− 4	115	119	− 4	118	123	− 5	119	125	− 6	111	113	− 2	114	116	− 2
4. Nightingale - -	...	129	...	...	...	...	121	120	+ 1	...	...	...	...	...	...	117	117	0	‡121	‡125	− 4
5. Spotted Flycatcher -	(131)	137	− 6	132	140	− 8	134	135	− 1	141	139	+ 2	141	158	−17	132	134	− 2	133	137	− 4
6. Swallow Last Seen -	272	275	− 3	275	275	0	284	279	+ 5	275	270	+ 5	272	260	+12	285	284	+ 1	280	278	+ 2
Mean of Nos. 2, 3 and 5	118	121	− 3	120	124	− 4	119	123	− 4	126	127	−1	126	136	−10	116	119	− 3	119	121	− 2
7. Honey Bee - -	78	73	+ 5	62	72	−10	53	64	−11	53	68	−15	53	66	−13	55	59	− 4	59	63	− 4
8. Queen Wasp - -	115	109	+ 6	118	121	− 3	115	111	+ 4	124	117	+ 7	(124)	120	+ 4	103	100	+ 3	110	106	+ 4
9. Small White Butterfly	111	115	− 4	118	124	− 6	117	119	− 2	129	129	0	(117)	134	−17	111	109	+ 2	114	115	− 1
10. Orange-Tip Butterfly	129	130	− 1	130	131	− 1	135	143	− 8	(149)	151	− 2	...	*148*	...	128	133	− 5	130	135	− 5
11. Meadow Brown Butterfly	159	165	− 6	160	167	− 7	174	167	+ 7	160	175	−15	[157]	*172*	−15	165	167	− 2	162	165	− 3
12. Humble Bee - -	97	...	...	140	...	...	101	...	...	114	...	...	108	...	...	97	...	...	101	...	...
Mean of Nos 7-11 -	118	118	0	118	123	− 5	119	121	− 2	123	128	− 5	...	128	...	112	114	− 2	115	117	− 2

* Averages of districts A, C, D, E, F, I. † The British Isles means in both Tables X. and XI. are the means of the separate districts. ‡ The difference between the dates for the Nightingale and the Cuckoo in those districts in which *both* have been recorded, has been used as a basis for deriving the British Isles means for Nightingale. Values given above in *italics* have been interpolated owing to lack of data and are approximate only.

TABLE XI.—ARRIVAL OF SPRING MIGRANTS, 1928.

STATIONS. (173 selected out of about 400 of our observers, besides several from periodicals.)	Mean Value.*	Chiffchaff (*Phylloscopus rufus*). 1	Wheatear (*Saxicola œnanthe*). 2	Willow Warbler (*Phylloscopus trochilus*). 3	Sand Martin (*Cotile riparia*). 5	Tree Pipit (*Anthus trivialis*). 6	Blackcap (*Sylvia atricapilla*). 7	Sandpiper (*Totanus hypoleucus*). 9	House Martin (*Chelidon urbica*). 10	Whitethroat (*Sylvia cinerea*). 11	Lesser Whitethroat (*Sylvia curruca*). 12	Sedge Warbler (*Acrocephalus phragmitis*). 13	Garden Warbler (*Sylvia hortensis*). 15	Swift (*Cypselus apus*). 16	Corncrake (*Crex pratensis*). 17	Turtle Dove (*Turtur communis*). 18	Nightjar (*Caprimulgus europæus*). 19	Mean of Nos. 1 to 5.	Mean of Nos. 6 to 12.	Mean of Nos. 13 to 20.
A (i.) o † Guernsey .	106.4	64	66	102	112	*102*	*100*	111	104	107	*109*	*114*	118	113	122	126	*130*	87.4	104.7	119.6
oe. Jersey .	106.9	*74*	*79*	*99*	102	102	100	100	*105*	113	*109*	114	115	*120*	*122*	112	*130*	92.2	104.3	118.3
A (ii.) 6a. Duloe .	110.4	83	*87*	101	*101*	*107*	96	*110*	101	113	*112*	*120*	*120*	110	*122*	*121*	*133*	95.0	111.0	121.9
6c. Lopwell .	114.2	99	99	106	101	106	109	112	116	116	107	121	121	124	122	120	139	101.8	111.0	124.8
8e. Plymstock .	111.4	93	100	*98*	105	101	107	108	120	*114*	111	114	*120*	117	116	117	*133*	100.2	110.1	119.5
11g. Colebrooke	111.0	93	*87*	*98*	*101*	*107*	*108*	*110*	105	110	*112*	*120*	*120*	117	122	123	*133*	94.6	109.0	123.0
12b. Bideford .	112.3	93	*87*	105	98	*107*	*108*	*110*	105	120	*112*	128	*120*	121	*122*	*121*	*133*	96.2	110.6	123.8
12e. Forda Moor	111.9	92	*87*	92	*101*	*107*	*108*	113	114	114	*112*	*120*	*120*	121	*122*	*121*	*133*	94.8	111.4	123.0
13c. Exeter .	111.3	93	*87*	97	97	*107*	97	*110*	109	111	*112*	*120*	*120*	125	*122*	*121*	*133*	94.2	108.0	124.9
14a. Umberleigh	111.0	94	*87*	*98*	101	*107*	*108*	101	107	*114*	*112*	*120*	*120*	117	*122*	*121*	128	94.8	108.4	123.3
15b. Colyford .	110.9	104	*87*	101	98	*107*	*108*	107	107	107	*112*	115	*120*	115	*122*	*121*	*133*	98.0	107.4	121.9
15c/e. Lyme Regis	111.2	87	82	*98*	*101*	*107*	*108*	*110*	*110*	115	*112*	*120*	*120*	119‡	*122*	*121*	*133*	93.0	110.7	123.0
19c. Bradney .	111.2	82	*87*	100	*101*	*107*	111	*110*	116	*114*	*112*	*120*	*120*	117	*122*	*121*	*133*	94.8	111.6	121.0
20a. West Porlock	110.2	81	76	83	95	114	113	112	116	112	*112*	*120*	*120*	114	*122*	126	*133*	86.0	112.4	123.4
24a. Pimperne .	110.6	83	71	99	*101*	*107*	112	*110*	114	113	114	*120*	119	129	*122*	119	*133*	91.0	110.6	122.8
25b/h. Flax Bourton	113.2	85	86	105	111	112	115	*110*	117	117	115	118	121	121	121	*121*	131	98.0	113.1	122.8
25c. Keynsham .	112.4	*89*	85	83	98	104	106	*110*	123	118	124	*120*	*120*	111	*122*	*121*	*133*	92.0	112.9	124.6
25f. Pensford .	113.1	93	*87*	98	*101*	*107*	112	118	116	117	*112*	*120*	126	122	*122*	117	*133*	97.8	112.0	123.6
27c. Portishead .	112.3	83	*87*	*98*	106	*107*	*108*	*110*	117	*114*	*112*	125	*120*	117	128	126	*133*	95.0	110.0	125.0
28b. Clevedon .	110.4	82	*87*	97	*101*	*107*	112	*110*	106	*114*	102	*120*	*120*	116	*122*	*121*	*133*	93.0	108.4	122.9
A (iii.) 28c. Cardiff .	112.3	92	90	97	100	101	*112*	*112*	105	110	110	*117*	*124*	119	*119*	*124*	*133*	97.0	109.4	124.4
28d. Llandaff .	110.2	85§	78¶	91	*97*	*110*	*112*	*112*	106	*114*	*114*	*117*	*124*	112	124	*124*	126	90.8	110.9	121.8
32a. Tenby .	112.9	99	*88*	103	101	*110*	119	*112*	101	119	*114*	115	*124*	122	119	*124*	128	98.4	112.4	122.4
32c. Pembroke .	112.8	96	88	*99*	106	*110*	*112*	*112*	113	112	*114*	*117*	*124*	*115*	115	124	*133*	99.2	112.0	121.9

		1	2	3	5	6	7	9	10	11	12	13	15	16	17	18	19			
34c. Philadelphia .	111.5	100	*88*	105	*97*	*110*	*112*	*112*	101	*114*	*114*	120	*124*	116	113	*124*	137	97.6	108.7	122.6
34d. Carmarthen .	111.7	82	*88*	*99*	*97*	120	*112*	116	103	120	*114*	117	*124*	111	117	*124*	*133*	95.6	112.4	121.1
43a. Hafod . .	113.7	84	*88*	100	*97*	*110*	118	*112*	*108*	117	*114*	*117*	120	121	*119*	*124*	*133*	97.4	113.6	122.6
43c. Aberystwyth .	110.8	85	78	97	85	104	119	112	104	113	126	113	127	112	116	*124*	141	88.4	113.3	122.5
44a. New Radnor .	110.3	100	104	*99*	94	110	98	107	109	104	107	120	125	110	121	*124*	133	97.6	106.4	121.5
B 6a. Timoleague. .	113.0	87	*90*	100	100	*111*	*110*	123	110	122	*114*	122	*118*	117	110	127	132	95.4	113.9	123.1
22b. Castle Lyons .	113.3	90	*90*	102	*105*	*111*	*110*	*120*	113	*115*	*114*	*120*	*118*	117	119	*121*	*132*	98.0	114.6	121.6
27a. Castleconnell .	112.5	90	*90*	101	99	*111*	*110*	*120*	*108*	*115*	*114*	*120*	*118*	117	120	*121*	*132*	96.0	113.9	121.5
27b. Corbally . .	110.1	83	*90*	96	90	*111*	*110*	*120*	106	104	*114*	*120*	*118*	117	119	*121*	*132*	91.0	112.0	120.3
38b. Borris . .	113.9	87	*90*	*100*	120	*111*	*110*	*120*	118	*115*	*114*	*120*	*118*	119	118	*121*	*132*	99.0	114.1	122.9
43b. Stradbally . .	112.9	83	*90*	99	110	*111*	*110*	*120*	113	*115*	*114*	*120*	*118*	122	111	*121*	*132*	97.2	114.3	121.4
52a. Portmarnock .	114.9	91	*90*	105	118	*111*	*110*	*120*	*108*	120	*114*	126	*118*	115	118	*121*	132	103.4	115.1	121.9
C 1‡‡ Bournemouth .	110.8	85	80	99	94	*105*	109	*114*	108	*112*	*118*	*112*	133	111	*119*	*122*	*128*	92.4	110.0	123.0
1g. Southbourne .	113.2	91	93	101	84	106	115	116	119	114	115	120	115	118	*119*	136	135	94.2	112.1	125.9
1b. Ringwood . .	106.7	93	*87*	93	80	*105*	*107*	*114*	106	100	*118*	107	111	112	116	124	123	91.8	107.7	115.0
1c. Lymington .	111.4	112	*87*	102	108	*105*	*107*	*114*	106	111	*118*	*112*	*118*	111	*119*	115	*128*	102.2	110.0	118.4
1i. Appleslade . .	111.1	90	*87*	97	*101*	*105*	117	*114*	105	117	*118*	114	116	118	*119*	121	118	96.0	111.7	120.0
2a. Mere . .	110.9	82	*87*	100	*101*	*105*	113	*114*	117	*112*	*118*	*112*	*118*	115	*119*	125	*128*	94.4	111.9	120.3
3a. Shanklin . .	110.0	91	89	101	103	*105*	103	*114*	103	117	117	117	117	115	*119*	131	*128*	95.6	107.4	121.1
3e/f Southsea . .	107.5	85	92	93	105	104	104	109	109	111	112	110	116	116	116	111	123	95.0	107.3	115.5
4b. Sherfield English	108.6	82	*87*	92	*101*	112	103	*114*	108	122	120	*112*	123	112	*119*	125	121	92.2	111.3	116.4
4d. Minstead . .	113.0	*88*	*87*	110	*101*	*105*	*107*	*114*	116	127	120	*112*	119	117	*119*	*122*	*128*	100.0	113.9	120.3
4e/g Romsey . .	107.4	82	*87*	92	*101*	*105*	103	*114*	108	*112*	*118*	*112*	*118*	112	*119*	125	121	92.2	108.6	115.8
5e. Steeple Ashton .	111.1	92	*87*	100	110	*105*	116	*114*	108	111	116	*112*	*118*	117	*119*	117	*128*	97.4	111.4	119.3
6a. Havant . .	109.4	85	81	98	*101*	102	119	*114*	106	115	126	*112*	*118*	108	*119*	125	118	90.4	111.7	119.1
6d/e. Hayling Island .	110.3	91	*87*	91	*101*	*105*	109	*114*	102	*112*	*118*	*112*	*118*	119	*119*	123	*128*	93.8	110.3	120.6
7a. Botley . .	107.5	86	*87*	100	92	111	95	*114*	111	110	*118*	*112*	111	114	*119*	117	*128*	93.0	108.4	115.8
7f. Sutton Scotney .	109.7	86	*87*	98	*101*	*105*	99	*114*	107	120	120	103	*118*	114	*119*	119	*128*	93.0	109.4	120.4

• The *Bird* values are the mean of all actual records (excluding those abnormally early or late), by districts, without any interpolation. The *Station* values are obtained by interpolating for blanks either the district mean, or a considered value from adjacent records. Such values are printed in *italics*. † Combination of the four stations Oa, b, d, f. ‡ Observed at Paignton. § At Pontychin 7 m. W. ¶ Near St. Davids. ‖ At Kenfig 25 m. W. of Llandaff. ‡‡ Combination of the three stations 1a, e, f.

NOTE.—For reason of space the following are omitted from the printed table, although included in the station means :—(4) Swallow, (8) Cuckoo, (14) Nightingale, (20) Spotted Flycatcher. They, of course, appear in Table IX.

TABLE XI.—ARRIVAL OF SPRING MIGRANTS, 1928—*continued.*

STATIONS.	Mean Value.	Chiffchaff (*Phylloscopus rufus*). 1	Wheatear (*Saxicola œnanthe*). 2	Willow Warbler (*Phylloscopus trochilus*). 3	Sand Martin (*Cotile riparia*). 5	Tree Pipit (*Anthus trivialis*). 6	Blackcap (*Sylvia atricapilla*). 7	Sandpiper (*Totanus hypoleucus*). 9	House Martin (*Chelidon urbica*). 10	Whitethroat (*Sylvia cinerea*). 11	Lesser Whitethroat (*Sylvia curruca*). 12	Sedge Warbler (*Acrocephalus phragmitis*). 13	Garden Warbler (*Sylvia hortensis*). 15	Swift (*Cypselus apus*). 16	Corncrake (*Crex pratensis*). 17	Turtle Dove (*Turtur communis*). 18	Nightjar (*Caprimulgus europæus*). 19	Mean of Nos. 1 to 5.	Mean of Nos. 6 to 12.	Mean of Nos. 13 to 20.
7h. Winchester	108.7	77	*87*	98	100	*105*	*107*	*114*	103	106	*118*	102	*118*	112	*119*	121	*128*	92.2	107.9	119.8
8b. Marlborough	112.5	85	82	99	*101*	98	*107*	*114*	126	107	138	128	125	117	*119*	122	*128*	93.8	114.4	122.5
10c. Littlehampton	114.2	97	92	99	110	108	114	111	107	117	*118*	118	121	118	123	*122*	141	103.2	111.4	123.5
11e. Chiddingfold	113.8	110	*87*	111	*101*	*105*	122	*114*	117	*112*	120	*112*	*118*	116	*119*	114	*128*	102.6	113.0	121.4
12b. Chilbolton	107.3	85	*87*	109	98	105	*107*	115	101	108	109	101	*118*	103	*119*	*122*	*128*	95.2	106.6	115.5
13a/b. Swindon	113.9	80	*87*	96	115	*105*	*107*	*114*	116	119	*118*	126	*118*	119	*119*	*122*	*128*	98.2	113.4	124.0
15g. Hassocks	109.9	92	93	97	*101*	*105*	105	120	106	116	104	113	114	122	*119*	117	125	97.2	108.1	119.3
16f. Odiham	111.3	100	*87*	84	*101*	*105*	*107*	*114*	114	*112*	*118*	*112*	*118*	130	*119*	119	*128*	94.4	109.9	123.1
16m. Godalming	111.4	86	91	99	*101*	94	109	*114*	*109*	127	123	*112*	*118*	111	*119*	131	*128*	97.0	110.7	121.0
18a. Lewes	105.5	80	78	97	98	100	94	111	108	102	117	99	108	114	*119*	117	*128*	90.0	104.9	115.8
18c. Ditchling	109.2	*88*	95	*98*	99	97	111	*114*	101	105	111	101	121	113	122	123	*128*	97.8	106.3	118.8
21b/e Hastings	108.4	77	99	97	115	101	92	118	114	108	115	116	108	115	*119*	117	*128*	97.2	108.6	115.3
21d. Rye	111.0	79	*87*	99	*101*	*105*	*107*	*114*	112	115	*118*	116	119	117	*119*	123	*128*	93.6	111.9	121.0
22b. Warlingham	110.3	85	*87*	*98*	*101*	*105*	*107*	*114*	*109*	114	119	*112*	119	126	*119*	113	128	93.8	111.1	119.8
22c. Purley	111.2	91	*87*	97	*101*	*105*	115	*114*	*109*	*112*	119	*112*	111	123	*119*	*122*	*128*	97.6	110.7	120.0
25f. Sutton Valence	111.6	104	*87*	*98*	*101*	*105*	120	*114*	102	102	*118*	*112*	*118*	125	*119*	*122*	126	98.8	109.1	121.6
D (i.) 4d. Staunton-on-Arrow	114.3	84	*91*	110	105	*114*	120	*115*	114	107	*117*	*110*	*123*	116	*123*	130	*127*	100.4	110.9	124.5
5d. Coaley	114.6	88	93	90	114	118	116	120	112	113	119	128	121	120	*123*	129	*127*	97.8	114.3	125.4
5e. Churchdown	113.4	93	*91*	*101*	*108*	*114*	*114*	*115*	117	*114*	109	*110*	*123*	119	120	137	*127*	99.0	112.9	122.8
5f. Cheltenham	110.3	86	*91*	94	104	*114*	96	*115*	107	104	118	*110*	*123*	115	118	126	*127*	94.0	109.4	121.1
6a. Dymock	114.7	97	*91*	102	*108*	*114*	*114*	*115*	*111*	124	*117*	*110*	*123*	125	*123*	128	*127*	100.2	114.0	124.3
9b/d. Bourton-on-the-Water	112.5	83	101	99	103	108	117	115	101	116	123	101	123	117	*123*	120	127	98.2	113.0	120.9

		1	2	3	5	6	7	9	10	11	12	13	15	16	17	18	19			
10b. Evesham . .	115.6	87	*91*	115	*108*	*114*	*114*	*115*	115	*114*	*117*	*110*	*123*	117	*123*	122	*127*	103.2	115.0	123.9
10d. Offenham . .	113.2	*89*	*91*	*101*	*108*	*114*	*114*	*115*	109	113	*117*	*110*	*123*	118	*123*	128	*127*	100.0	112.1	122.3
10e/f. West Malvern .	112.7	96	81	99	99	*114*	115	*115*	116	*114*	*117*	*110*	*123*	115	*123*	*127*	*127*	94.4	114.1	122.9
11a. Tenbury . .	114.7	84	*91*	100	*108*	117	*114*	*115*	104	116	118	*110*	129	116	135	130	*127*	96.8	113.1	127.1
16b. Cookley, Wolverley	112.7	81	*91*	99	107	*114*	101	109	107	109	122	*110*	*123*	117	*123*	125	*127*	97.0	110.6	124.3
16f. Frankley . .	112.6	99	91	105	115	104	*114*	*115*	119	98	100	*110*	*123*	*117*	*123*	*127*	*127*	101.0	108.9	123.1
17b. Newport . .	114.3	85	*91*	101	104	116	124	*115*	104	117	*117*	*110*	118	*117*	*123*	131	*127*	96.4	115.6	124.3
17d. Benthall . .	113.4	83	*91*	100	104	120	116	*115*	*111*	116	*117*	*110*	120	113	125	126	*127*	96.8	115.0	122.4
D (ii) 8a. Goring . .	112.7	83	*93*	*98*	80	*109*	*111*	116	120	*115*	*120*	*114*	*122*	125	*128*	122	*124*	92.6	114.9	123.3
13d. Beaconsfield .	112.3	86	*93*	99	101	104	104	*114*	112	119	*120*	112	118	116	*128*	123	*124*	98.2	111.7	121.6
15a. Whernalls . .	111.3	82	*93*	97	*100*	97	118	*114*	102	*115*	*120*	*114*	*122*	118	*128*	118	*124*	95.8	110.6	121.6
15c. Stratford-on-Avon	111.5	83	*93*	98	*100*	*109*	105	*114*	101	115	*120*	*114*	*122*	126	122	*123*	*124*	95.4	109.4	123.5
15d. Pillerton Hersey .	112.8	84	*93*	98	*100*	*109*	*111*	*114*	114	113	*120*	*114*	*122*	*121*	*128*	124	*124*	95.4	113.4	123.1
16e. S. Birmingham .	111.5	*88*	*93*	*98*	*100*	*109*	*111*	109	109	109	117	117	122	117	*128*	118	*124*	97.2	110.6	121.3
19b. Granborough .	112.7	86	*93*	97	*100*	*109*	*111*	*114*	112	116	119	*114*	*122*	117	*128*	*123*	*124*	97.6	114.0	121.0
21h. Blackdown .	115.3	92	*93*	97	*100*	120	117	*114*	113	118	*120*	*114*	119	125	134	*123*	*124*	97.2	116.9	125.3
26b. Sutton Coldfield .	117.5	102	103	102	*100*	114	*111*	116	125	117	119	*114*	126	121	*128*	135	*124*	103.0	117.6	126.5
D (iii) 35a. Somershall Herbert .	115.9	*99*	100	100	117	109	119	*113*	114	118	121	*116*	124	117	*127*	*130*	*130*	104.6	115.6	123.1
39d/e. Sheffield . .	116.9	101	100	100	*111*	*116*	*119*	*113*	123	*117*	*121*	*116*	*125*	120	120	*130*	*130*	105.4	117.9	123.1
44f. Ackworth . .	117.9	*99*	*104*	101	*111*	119	*119*	*113*	*116*	119	*121*	*116*	*125*	122	*127*	136	*130*	103.4	117.7	127.3
49c. Bolton Percy .	117.8	*99*	*104*	101	*111*	*116*	*119*	*113*	122	119	*121*	*116*	126	127	126	134	*130*	104.2	118.9	125.4
49d. Kirk Deighton .	115.5	*99*	113	*105*	106	*116*	*119*	*113*	106	113	*121*	*116*	*125*	114	126	*130*	*130*	106.8	112.9	123.1
E 1* Barnet . .	112.0	97	91	97	*109*	*106*	120	*112*	105	105	116	*118*	120	118	*123*	*123*	*127*	101.0	109.0	121.5
2e. Aldbury . .	109.5	*90*	*88*	*101*	*109*	*106*	111	*112*	92	107	*113*	*118*	*121*	111	*123*	*123*	*127*	98.8	105.6	119.6
3d. Warley . .	110.7	82	*88*	*101*	94	116	*108*	*112*	111	103	*113*	124	117	117	*123*	124	*127*	92.6	110.6	122.1
4i. Hitchin . .	108.3	82	102	100	114	103	101	*112*	103	103	104	*118*	123	116	124	100	*127*	99.0	103.9	117.9
5a. Turvey . .	111.3	88	*88*	101	*109*	114	100	*112*	*109*	101	*113*	123	126	120	121	122	*127*	97.0	107.3	123.7
7b. Sawbridgeworth .	112.4	100	104	98	105	99	100	112	106	118	119	123	*121*	127	*123*	123	*127*	101.2	108.9	122.5
8a/b. Letchworth .	106.2	83	78	100	100	100	102	*112*	103	103	104	113	120	122	124	100	*127*	91.6	103.6	117.6
8e/f. Kempston .	111.3	83	*88*	98	107	108	116	*112*	107	108	*113*	116	115	117	*123*	*123*	*127*	96.6	110.6	121.3
11d/f. Cambridge .	111.5	90	75	98	102	117	114	*112*	98	114	115	117	*121*	135	*123*	132	*127*	92.6	110.0	125.9

* Combination of the four stations 1b, c, d, f.

TABLE XI.—Arrival of Spring Migrants, 1928—*continued.*

Stations.	Mean Value.	Chiffchaff (*Phylloscopus rufus*). 1	Wheatear (*Saxicola œnanthe*). 2	Willow Warbler (*Phylloscopus trochilus*). 3	Sand Martin (*Cotile riparia*). 5	Tree Pipit (*Anthus trivialis*). 6	Blackcap (*Sylvia atricapilla*). 7	Sandpiper (*Totanus hypoleucus*). 9	House Martin (*Chelidon urbica*). 10	Whitethroat (*Sylvia cinerea*). 11	Lesser Whitethroat (*Sylvia curruca*). 12	Sedge Warbler (*Acrocephalus phragmitis*). 13	Garden Warbler (*Sylvia hortensis*). 15	Swift (*Cypselus apus*). 16	Corncrake (*Crex pratensis*). 17	Turtle Dove (*Turtur communis*). 18	Nightjar (*Caprimulgus europæus*). 19	Mean of Nos. 1 to 5.	Mean of Nos. 6 to 12.	Mean of Nos. 13 to 20.
12a. Keysoe	113.0	84	*88*	100	*109*	*106*	118	*112*	112	118	115	*118*	*121*	*120*	116	134	*127*	96.0	113.6	123.1
13c. Frinton	113.1	*90*	115	*101*	115	*106*	*108*	*112*	*109*	119	106	119	*121*	*120*	*123*	*123*	*127*	104.0	111.3	120.5
14a. Ballingdon	113.7	*90*	*88*	101	*109*	118	*108*	*112*	*109*	113	128	*118*	123	127	*123*	123	*127*	97.4	114.4	123.3
14d. Denston	111.6	105	70	113	*109*	92	97	*112*	117	*112*	*113*	*118*	109	*120*	*123*	*123*	*127*	102.8	107.9	120.4
17e. Boxford	114.3	107	*88*	112	*109*	*106*	108	*112*	*109*	*112*	*113*	*118*	*121*	*120*	*123*	127	*127*	103.2	110.9	124.4
22b. Langford	113.1	108	84	102	119	*106*	*108*	*112*	106	114	110	117	*121*	126	*123*	131	*127*	103.2	108.6	123.1
22d. Grimston, Lynn	112.3	106	85	106	108	*106*	103	*112*	109	118	*113*	120	*121*	109	*123*	*123*	*127*	101.2	108.9	122.4
26a. Hemsby	113.9	82	82	108	120	*106*	121	*112*	110	120	*113*	*118*	131	131	*123*	131	*127*	98.4	112.1	125.1
26c. Blofield	111.9	98	*88*	107	106	98	101	*112*	113	118	*113*	*118*	*121*	119	*123*	127	*127*	100.2	108.0	122.6
27b. Holt	109.9	85	78	92	115	*106*	*108*	*112*	107	108	112	*118*	*121*	*120*	*123*	119	*127*	93.4	109.4	120.6
F (i.) 2a/d. Aberdovey	111.7	87	78	97	*113*	*118*	123	111	107	114	*120*	112	122	112	*121*	*126*	*127*	94.2	115.7	119.3
9b. Deganwy	113.2	96	82	100	110	*118*	*118*	*106*	106	127	*120*	*117*	*117*	118	*121*	*126*	*127*	99.2	114.4	120.9
11h. Abergele	114.2	*89*	*81*	*98*	111	*118*	*118*	*106*	113	113	120	122	124	125	124	*126*	*127*	97.8	114.1	124.5
F (ii.) 14a. Barnton	111.4	92	88	102	102	*116*	102	102	101	102	120	119	*123*	124	123	*128*	*129*	96.8	108.0	123.5
14b. Altrincham	115.5	111	*91*	106	111	*116*	*114*	*112*	114	106	*120*	120	*123*	114	120	128	132	106.4	113.3	123.1
14d. Stockton Heath	115.1	*97*	*91*	102	109	*116*	*114*	112	113	119	*120*	113	*123*	124	*124*	*128*	*129*	100.6	115.7	123.5
15a. Southport	113.7	*97*	80	100	92	*116*	*114*	108	*114*	118	*120*	118	*123*	*122*	*124*	*128*	*129*	95.8	115.0	123.9
16b. Bramhall	115.6	96	96	101	*109*	*116*	*114*	*112*	112	112	122	*119*	*123*	122	133	*128*	133	100.8	114.1	126.1
16c. Cheadle Hulme	112.3	79	79	103	105	*116*	*114*	*112*	104	*115*	*120*	116	*123*	120	121	*128*	*129*	94.0	113.7	122.4
16d. Alderley Edge	116.7	*97*	*91*	104	112	115	*114*	*112*	117	*115*	119	*119*	*123*	129	*124*	*128*	*129*	103.4	115.4	126.1
16e. Prestbury	115.9	78	*91*	102	113	120	120	115	113	118	124	*119*	120	125	*124*	*128*	*129*	97.2	118.6	125.1
18b. Marton Mere	113.7	93	95	103	107	107	109	106	118	116	115	127	*123*	118	123	*128*	*129*	101.4	110.6	124.3
22b. Ulverston	116.9	102	*91*	102	119	119	120	124	122	118	*120*	118	120	119	*124*	*128*	*129*	102.8	120.0	123.1

		1	2	3	5	6	7	9	10	11	12	13	15	16	17	18	19			
22d. Grange-over-Sands	116.1	*97*	*91*	*105*	*109*	*116*	*114*	*112*	116	119	*120*	*119*	*123*	122	131	*128*	126	103.0	116.3	124.1
24a. Arnside . .	114.7	*97*	96	102	98	*116*	119	*112*	119	118	*120*	118	*123*	118	120	*128*	*129*	98.2	117.1	122.9
25a/b. Ambleside . .	114.1	107	84	101	105	114	107	107	110	118	*120*	122	120	117	131	*128*	126	101.0	113.1	123.1
28a/d. Keswick . .	114.7	99	92	106	*109*	*116*	*114*	*112*	*114*	*115*	*120*	*119*	119	118	118	*128*	*129*	101.6	115.4	122.3
31b. Carlisle . .	117.2	*97*	90	106	118	*116*	*114*	127	117	115	*120*	*119*	131	129	122	*128*	129	103.2	117.4	125.7
32a. Alston . .	118.7	*97*	*91*	115	118	118	*114*	*112*	*114*	*115*	*120*	*119*	126	133	*124*	*128*	*129*	107.6	115.9	128.0
G 2a. Loughrea . .	115.8	106	106	104	*92*	112	105	119	*108*	124	*115*	*119*	*120*	*119*	*117*	139	*134*	103.0	114.6	124.9
35c/e. Warrenpoint .	111.3	102	*98*	99	92	*106*	*108*	*118*	100	117	*115*	118	*120*	108	117	*125*	*134*	96.6	111.1	120.5
41c. Scarva . .	113.2	*97*	*98*	110	100	*106*	*108*	*118*	106	104	*115*	*119*	*120*	123	*117*	*125*	*134*	102.0	108.9	123.6
50c. Belfast . .	112.6	92	93	103	84	96	*108*	*118*	118	120	*115*	*119*	*120*	*119*	*117*	*125*	*134*	94.4	113.6	123.1
50f. Woodbourne .	109.3	92	95	103	84	*106*	*108*	*118*	100	103	107	*119*	110	108	110	*125*	*134*	94.6	108.0	119.6
54a. Hazelbank . .	116.5	97	98	105	100	109	111	117	119	124	123	119	*120*	126	118	128	*134*	101.4	116.7	125.6
H (i.) oa. Baldrine, I. of M.	112.2	80	82	95	91	110	*109*	113	118	108	*120*	122	128	123	117	*129*	133	90.0	113.7	124.7
oc. Lezayre ,,	117.1	97	*90*	109	*111*	*110*	*109*	*113*	*118*	127	*120*	120	*128*	*129*	120	*129*	*133*	104.2	116.4	125.6
H (ii.) 1a. Drummore .	112.9	87	85	101	*113*	*108*	*106*	111	117	112	116	115	*128*	120	117	118	*137*	98.2	111.6	123.4
11a. Collin . . .	116.5	*93*	91	*103*	116	*108*	106	*111*	125	115	127	118	*128*	134	119	*119*	*137*	103.6	115.3	125.7
18a. Dumfries . .	113.9	*93*	*87*	*103*	101	*108*	*106*	*111*	*117*	*115*	*122*	*116*	*128*	120	131	*119*	133*	98.4	113.1	124.4
20b. Hareshawmuir .	113.9	*93*	76	102	*113*	*108*	*106*	103	116	*115*	*122*	*116*	*128*	*119*	*122*	*119*	*137*	97.2	112.1	125.7
27f. Glasgow . .	113.5	100	83	100	*113*	109	*106*	103	116	118	*122*	119	133	118	118	*119*	140	99.6	112.1	123.3
30a. Cairndow . .	114.8	*93*	*87*	101	113	*108*	*106*	116	*117*	*115*	*122*	111	*128*	*119*	*122*	121	*137*	101.4	114.3	123.6
33c. Ledaig . .	116.1	*93*	98	101	118	117	*106*	*111*	116	*115*	*122*	*116*	*128*	122	*122*	*119*	*137*	105.4	114.7	124.0
I 6a. Lincoln . .	116.8	100	101	102	109†	*114*	112	*115*	115	121	*122*	121	122	126	*125*	128	*129*	103.4	116.3	125.6
8a. Woodhall Spa .	118.5	*99*	*93*	99	115	116	*116*	*115*	*118*	124	120	*118*	*124*	*123*	*125*	*128*	*129*	104.2	118.0	128.0
11c. New Waltham .	117.7	97	*93*	100	118	117	120	*115*	126	119	126	113	131	120	*125*	134	*129*	104.2	118.1	125.9
11f. Limber . .	116.3	91	*93*	99	120	115	114	*115*	122	114	120	113	*124*	120	*125*	128	*129*	103.2	116.7	124.3
12a. Holderness . .	115.2	98	*93*	100	108	114	*116*	*115*	*118*	117	122	109	133	116	132	119	127	100.2	116.0	123.9
14a. York . . .	114.8	92	75	106	99	*114*	*116*	120	123	118	*122*	120	*124*	133	118	*128*	*129*	94.2	117.0	125.9
18a. Middleton-in-Teesdale .	116.9	*99*	86	103	115	114	*116*	117	116	*118*	*122*	*118*	122	131	*125*	*128*	*129*	102.8	117.1	125.4
21a. Hull . . .	117.7	98	104	102	108	119	121	116	120	118	118	122	122	121	122	133	133	104.2	117.7	126.0
21b. Skidby . .	116.1	106	77	*102*	107	*114*	108	*115*	113	*118*	*122*	*118*	*124*	133	*125*	*128*	*129*	101.0	115.1	126.5

* Observed at Dalbeattie. † At Blylon, 18 m. NW.

TABLE XI.—ARRIVAL OF SPRING MIGRANTS, 1928—*continued.*

STATIONS.	Mean Value.	Chiffchaff (*Phylloscopus rufus*). 1	Wheatear (*Saxicola œnanthe*). 2	Willow Warbler (*Phylloscopus trochilus*). 3	Sand Martin (*Cotile riparia*). 5	Tree Pipit (*Anthus trivialis*). 6	Blackcap (*Sylvia atricapilla*). 7	Sandpiper (*Totanus hypoleucus*). 9	House Martin (*Chelidon urbica*). 10	Whitethroat (*Sylvia cinerea*). 11	Lesser Whitethroat (*Sylvia curruca*). 12	Sedge Warbler (*Acrocephalus phragmitis*). 13	Garden Warbler (*Sylvia hortensis*). 15	Swift (*Cypselus apus*). 16	Corncrake (*Crex pratensis*). 17	Turtle Dove (*Turtur communis*). 18	Nightjar (*Caprimulgus europæus*). 19	Mean of Nos. 1 to 5.	Mean of Nos. 6 to 12.	Mean of Nos. 13 to 20.
24b. Darlington .	115.1	97	97	101	105	112	118	112	117	117	125	*118*	118	119	115	*128*	*129*	100.6	116.7	122.7
26a. Catcleugh .	115.6	103	83	103	103	121	*116*	103	119	108	*122*	*118*	*124*	*123*	134	*128*	*129*	101.4	114.6	125.5
33b. Chopwell .	116.1	*99*	112	101	115	102	*116*	116	117	112	*122*	*118*	119	125	119	*128*	117	108.8	114.6	122.0
38b. Waren .	115.7	*99*	*93*	99	116	*114*	*116*	110	120	*118*	*122*	*118*	*124*	118	120	*128*	*129*	101.4	116.7	124.0
38c. Lemmington	118.3	101	102	111	116	101	123	122	102	126	125	117	123	117	130	*128*	138	108.2	116.1	126.6
38d. Little Mill .	119.2	115	100	102	96	119	128	115	125	122	*122*	126	*124*	126	130	*128*	*129*	102.0	122.7	126.9
J 4a. Selkirk .	119.5	*103*	98	100	105	117	127‡	112	118	127	*131*	120	127	115	128	*133*	*140*	102.2	121.3	128.7
6b. Jedburgh .	120.6	*103*	*94*	101	*113*	*117*	*120*	*117*	124	118	*131*	*129*	*131*	118	123	*133*	*140*	105.6	120.4	130.1
20a. Loch Tummel	121.9	*103*	86	102	*113*	116	*120*	115	126	*130*	*131*	132	131	127	133	138	*140*	101.8	122.4	134.1
36a. Cabrach .	128.9	103	103	131	126	118	113	113	136	141	141	141	143	145	*128*	*133*	*140*	118.8	125.7	138.1
39a. Dunlugas .	121.3	*103*	*94*	106	111	116	121	124	119	123	129	126	121	129	123	*133*	*140*	106.8	122.1	129.6
39b. Forglen .	122.9	*103*	*94*	111	118	*117*	*120*	124	116	*130*	*131*	125	*131*	130	134	*133*	*140*	109.8	121.3	132.5
K 24b/c. Muir of Ord	123.5	*110*	107	126	129	*117*	*120*	*117*	118	*121*	*126*	*126*	*130*	136	125	*133*	*140*	116.0	119.6	131.7
24e. Beauly .	124.3	*110*	118	120	116	*117*	*120*	119	*121*	118	*126*	131	*130*	135	123	*133*	*140*	116.8	119.7	133.1
27b. Kirkhill .	123.7	*110*	119	120	108	*117*	*120*	114	120	125	*126*	*126*	*130*	*130*	123	*133*	*140*	115.2	121.1	131.3

‡ At Merton, 12 m. away.

		1	2	3	5	6	7	9	10	11	12	13	15	16	17	18	19			
Total records used=3348	...	228	121	234	156	87	115	69	236	171	79	96	86	270	137	108	46	...	...	...
Mean of—																				
A (8) England SW.	111.1	88	84	98	99	109	107	111	108	113	113	117	122	117	121	122	133	99.4	110.1	122.3
B (10) Ireland S.	114.1	89	[103]	100	105	*111*	*110*	[123]	108	115	*114*	(124)	*118*	117	116	[127]	(132)	100.4	114.0	122.6
C (5) England SE.	110.5	88	87	98	101	105	107	114	109	112	118	112	118	117	119	122	128	95.6	110.0	120.1
D (4) England Mid.	113.9	89	98	101	104	113	112	112	112	114	118	112	123	118	125	127	(127)	99.8	113.3	123.1
E (3) England E.	111.8	90	88	101	109	106	108	[112]	109	112	113	118	121	120	123	123	[127]	98.6	109.7	121.9
F (7) England NW.	114.1	95	87	104	107	116	113	110	112	115	120	119	121	121	123	(123)	129	100.2	114.3	122.6
G (9) Ireland N.	113.3	97	98	103	92	106	(108)	(118)	108	117	(115)	(119)	[110]	119	117	(133)	*134*	99.4	112.4	122.9
H (6) Scotland W.	114.9	(93)	87	103	113	108	[106]	111	117	115	122	116	[133]	119	122	(119)	(137)	101.4	113.6	124.6
I (2) England NE.	116.7	99	93	102	110	114	116	115	118	118	122	118	124	123	125	128	129	102.6	116.9	125.3
J (1) Scotland E.	123.1	[103]	94	110	113	117	120	117	125	130	(135)	129	131	129	128	[138]	*140*	107.6	123.1	132.7
K (0) Scotland N.	123.5	*110*	105	120	114	[117]	*120*	117	121	(121)	*126*	[131]	*130*	(135)	126	*133*	*140*	113.4	120.1	132.9
Sub-Districts—																				
A (i.) Channel Isles	108.1	74	79	[102]	(107)	[102]	[100]	(105)	(105)	(110)	*109*	[114]	120	(120)	[122]	122	*130*	93.4	104.9	120.1
A (ii.) Eng. SW. only	111.7	89	87	98	101	107	108	110	110	114	112	120	120	119	122	121	133	95.8	110.1	123.0
A (iii.) S. Wales	111.9	90	88	99	97	110	112	112	108	114	114	117	124	115	119	[124]	133	95.4	111.6	122.4
D (i.) Eng. W. Mid.	113.7	89	91	101	108	114	114	115	111	114	117	110	123	117	123	127	(127)	99.0	113.6	123.1
D (ii.) Eng. E. Mid.	113.6	88	[103]	98	100	109	111	114	114	115	120	114	122	121	(128)	123	*124*	99.2	113.3	122.9
D (iii.) Eng. N. Mid.	117.3	[101]	104	105	(111)	116	[119]	*113*	116	117	[121]	*116*	(125)	120	127	(135)	*130*	106.2	117.0	124.6
F (i.) N. Wales	118.1	89	81	98	113	*118*	[123]	(106)	109	117	[120]	(117)	117	120	121	*126*	*127*	98.2	114.7	121.1
F (ii.) Eng. NW. only	115.5	97	91	105	109	116	114	112	114	115	120	119	123	122	124	[128]	129	102.2	115.3	124.0
H (i.) Isle of Man	114.5	89	(90)	101	[91]	[110]	*109*	[113]	[118]	(117)	[124]	123	[128]	129	117	*129*	[133]	95.2	115.7	125.6
Mean of all Districts	115.2	93.1	93.1	103.6	106.1	111.1	110.8	114.5	113.4	116.5	119.6	119.5	122.6	121.4	122.3	126.2	130.3	101.0	114.3	124.9
Month and Day	A.24	A. 2	A. 2	A.13	A.15	A.20	A.20	A.23	A.22	A.25	A.29	A.28	My. 2	A.30	My. 1	My. 5	My. 9	A. 10	A. 23	My.4
Average 15 yrs., 1914-28	117.2	95.7	96.5	105.7	109.7	112.0	112.5	114.8	116.7	119.0	119.5	121.5	123.8	124.1	124.6	126.8	132.8	103.7	115.8	126.9
„ N.H.J., 1877-96	113.1	94	93	103	106	107	110	117	111	113	118	115	125	125	121	123	129	...	...	...
Diff. from 15 yrs.'Avge.	−2	−2½	−3½	−2	−3½	−1	−1½	−½	−3½	−2½	0	−2	−1	−2½	−2½	−½	−2½	−2½	−1½	−2
H 27f. Average, 20 yrs.*	...	101	87	104	99	113	130	104	113	122	...	123	129	121	114	...	134	...	...	...

* Average of observations taken in the Clyde Valley, near Glasgow, during twenty years, 1908-27

TABLE XII.—Arrival of Rarer Spring Migrants.

British Isles Means.	Ring Ouzel (*Turdus torquatus*).	Wryneck (*Iynx torquilla*).	Yellow Wagtail (*Motacilla Raii*).	Redstart (*Ruticilla phœnicurus*).	Reed Warbler (*Motacilla arundinacea*).	Grasshopper Warbler (*Locustella nævia*).	Whinchat (*Pratincola rubetra*).	Wood Warbler (*Phylloscopus sibilatrix*).	Pied Flycatcher (*Muscicapa atricapilla*).	Red-Backed Shrike (*Lanius collurio*).	Mean.
Total Records Used	30	41	65	57	47	39	61	67	33	26	...
Mean 1928 . . Month and Day .	104.2 A. 13	105.4 A. 14	111.2 A. 20	114.1 A. 23	119.7 A. 29	120.4 A. 29	119.3 A. 28	122.1 My. 1	122.6 My. 2	132.7 My. 12	117.2 A. 26
Average 15 years, 1914-28 . .	98.2	104.2	113.6	115.8	119.9	120.5	120.6	122.0	125.3	130.5	117.1
Diff. from Average	+6	+1	−2½	−1½	0	0	−1½	0	−2½	+2	0

(*Continued from page* 256.)

movements most irregular; redwings 14 days after fieldfares. Few of migrants occur here, no swallow in '28, cuckoo 8 to 14 days early.

Geese Records.—B13a, 20 sets, some of 15 birds, dark grey, inland from Atlantic at Skibbereen. B27b, October 25. D36b, heard by night October 6. 49d, 37 flying S. E27b, 13 pink-footed September 20. F22b, September 27 passing S., clear night. 28a, flying N., February 17. G2a, Barnacle, October 20. 55b, grey lag and others early October. Hob, eastwards from sea, March 4/5. 30a, grey, southward, October 5. I9a, 3 flocks S.E., November 7. J19a, big flock from N.E., noisy and erratic, April 28; to S.E., October 22. 21b, April 21, 4 flocks, 153 in all, over Tayport, October 3. 36a, flying N., November 11; April 11, ditto N.W., also 25th, from L. Strathbeg, Aberdeen, to west coast and lochs. K24b, gaggle of 40 grey lags going N., April 23; ditto, on 29th southwards and 30th northwards.

Swallow tribe.—A17c, came late, left early. 25b, some had 3 broods, 2 only in previous 8 years. 34e, September 18-21, swallows daily into school, never rest of year, excited. November swallows several days. B13a, gathering swallows enter cottage, September 1/2. 27a, all numerous. 49b, swifts increasing again. C1e, swifts 10 days early. 6e, very late house martins, up to November. 15g, swifts still, October 24. 19d, swallows less, swifts and martins more. 4a, more martins than for years. 39e, no swifts over Sheffield. E14d, no swifts, swallows few and late. F32a, swifts left end July. G2a, few broods, due to wet summer. G35c, all numerous, swifts very early. H18b, late hatched swifts left late. 18a, few martins, plagued by sparrows. 18c, only one pair swifts, not nesting. I38b, swift, April 27, a record. J19a, martins few and late. Also noted as scarcer:—A12e, house martin; B14a, swallow; 43b, sand martin; C3a, swallow, save at migration, and swift; 10f, all getting fewer; 16f, swallow.

TABLE XIII.—Additional Bird Records.

District.	First Song.						Autumn Migration.						
	Missel Thrush 1	Song Thrush 2	Blackbird 3	Lark 4	Mean of Nos. 1-4	Cuckoo Last Heard 5	Last Swift 6	Last Sand Martin 7	Last Swallow 8	Last House Martin 9	First Redwing 10	First Fieldfare 11	Mean of Nos. 6-11
(8) England SW. .	13	12	27	40	23.0	177	237	276	284	278	294	295	277.3
(10) Ireland S. . .	13	12	30	33	22.0	172	223	[288]	282	270	285	301	274.8
(5) England SE. .	16	14	38	32	25.0	175	232	279	290	288	299	300	281.3
(4) England Mid. .	18	19	40	34	27.7	176	234	271	281	283	298	307	279.0
(3) England E. .	14	13	33	22	20.5	178	242	277	287	284	293	292	279.2
(7) England NW. .	22	17	32	36	26.7	181	237	(267)	281	277	301	300	277.2
(9) Ireland N. .	16	16	41	40	28.3	162	244	273	272	273	287	285	272.3
(6) Scotland W. .	43	24	48	45	40.0	175	247	[280]	275	269	297	294	277.0
(2) England NE. .	21	21	39	38	29.7	185	247	269	284	279	287	294	276.7
(1) Scotland E. .	43	35	44	45	41.7	175	240	262	275	267	287	284	269.2
(0) Scotland N. .	22	35	59	42	39.5	182	[243]	...	272	(248)	287	286	...
Sub-Districts :—													
(i) Channel Isles .	...	5	36	31	...	171	[232]	...	[302]	[279]	[304]	[305]	...
(ii) Eng. SW. only .	13	10	26	39	22.0	176	236	276	284	279	294	294	277.2
(iii) S. Wales .	13	18	32	45	27.0	180	237	...	285	275	(299)	(297)	...
(i) Eng. W. Mid. .	14	15	34	32	23.7	176	232	(259)	284	283	299	304	276.8
(ii) Eng. E. Mid. .	15	17	45	33	27.5	177	238	278	280	282	298	313	281.5
(iii) Eng. N. Mid. .	27	28	49	41	36.3	175	(233)	...	275	...	[292]	(301)	...
(i) N. Wales .	18	15	27	29	22.3	184	233	...	279	281	[312]	(308)	...
(ii) Eng. NW. only .	23	18	35	41	29.3	178	237	(267)	283	276	300	298	276.8
(i) Isle of Man .	17	22	30	(57)	31.5	...	247	...	300	[254]	(293)	(290)	...
otal Records Used .	179	298	203	181	...	143	132	44	258	139	85	100	...
ean of All Districts .	21.9	20	39.2	37.0	29.5	176.2	238.7	274.2	280	274.2	292.3	294.4	275.6
onth and Day . .	J. 22	J.20	F. 8	F. 6	J. 29	Je. 24	Ag. 26	S. 30	Oc. 6	S. 30	Oc.18	Oc. 20	Oc. 2
verage, 12 yrs. 1915-26	18.4	* 23	41.2	41.9	31.2	179.0	230.4	271.2	*278	279.7	294.3	298.9	275.4
onth and Day . .	J.18	J.23	F.10	F.11	J.31	Je. 27	Ag.17	S.27	Oc. 4	Oc. 6	Oc.20	Oc. 25	Oc. 1

* Average for 35 years, 1891-1925.

General Increases.—Cuckoo in parts; corncrake at B22b, I14a, 33b; wood pigeon, thousands at C7f to hundreds in '27; gold finches again.

Decreases.—Corncrake (passim); common birds in places, due to motors, says A15d; redstart; fieldfare at B43b, though redwings more; both at 51a; wryneck; C3f, no Dartford warblers, from gorse burning; warblers generally in several places; C14a, 21b, wheatear; 16f, 25g, etc., nightjar, spotted flycatcher; G2a, many corncrake broods destroyed, because late, by mowing; K43a, never any woodcock.

OTHER VERTEBRATES.—A6a, locally many fox, badger, otter, dormouse; 17b, February 27, slow worm; March 4, lizard. 30a, toad spawn, March 28. C4b, 2 adders killed, March 7; 2 grass snakes basking, though frosty, 14th, usual date; numerous later. D15c, first frog spawn killed by frost (as elsewhere). J19a, very few frogs, no spawn seen. K18e, first frog April 28, toad May 1.

TABLE XIV.—OBSERVATIONS OF PLANTS AND BIRDS TAKEN AT HEVINGHAM, NORFOLK, 1928, BY MAJOR H. S. MARSHAM.

PLANTS. (First Flowering, Fl., or Leafing, L.).	Total Yearly Records.	Average.			1928.	Difference from Average, 1891-1925.
		All Years.	35 Years, 1751-85.	35 Years, 1891-1925.		
*Snowdrop Fl. . .	149	16	19	19	23	+ 4
Wood Anemone Fl.	124	85	91	79	63	— 16
*Hawthorn Fl. . .	147	132	131	132	131	— 1
Turnip Fl. . . .	121	96	96	108	106	— 2
Hawthorn L. . .	155	68	72	71	19	— 52
Sycamore L. . .	145	93	96	90	78	— 12
*Birch L. . . .	145	94	92	97	80	— 17
Elm (Common) L.	118	94	90	102	94	— 8
Mountain Ash L. .	135	96	96	96	88	— 8
*Oak L.	148	115	118	110	104	— 6
*Beech L. . . .	148	113	116	113	104	— 9
*Horse Chestnut L.	143	94	96	96	88	— 8
Chestnut L. . . .	125	109	115	109	94	— 15
Hornbeam L. . .	130	97	103	101	101	0
Ash L.	128	119	122	118	112	— 6
*Lime L.	137	104	105	102	88	— 14
Maple L.	88	106	110	107	103	— 4
Mean of all 17. .	. .	96	100	97	87	— 10

BIRDS, &c. (First Appearance or Song).	Total Yearly Records.	Average.			1928.	Difference from Average, 1891-1925.
		All Years.	35 Years, 1751-85.	35 Years, 1891-1925.		
Swallow	156	109	105	113	111	– 2
Cuckoo	161	115	115	113	116	+ 3
Nightingale. . .	118	116	117	118	...	...
Nightjar	68	144	142	...	...	...
Thrush	134	27	37	28	16	–12
Ringdove ‡ . . .	105	53	54	...	120	– 7
Rooks Build . .	150	61	64	62	65	– 3
Young Rooks . .	147	102	102	104	101	+ 3
Yellow Butterfly .	131	78	71	91	64	–27
Frogs Croak . .	146	84	82	89	100	+11
Mean of all 10. .	. .	89	89	91½	...	...

COMPARISON WITH THE SOCIETY'S SERIES.

Mean of 7 Plants* . . .	95	97	96	88	– 8
Mean of Society's 7 Plants (Dist. E.). † .	...	...	93	88	– 5
Swallow (Society's Mean in Dist. E) . .	...	...	109	105	– 4
Cuckoo (Society's Mean in Dist. E) . .	...	...	111	108	– 3

* The seven plants used for comparison are marked *.

† The first seven plants, hazel to hawthorn, in the Society's list.

‡ Until 1915 this referred to *any* pigeon cooing, but is now strictly confined to the Turtle Dove. The average for the last 14 years is 127 (May 6).

This fine record was commenced in 1736. For full details see *Q.J.R. Meteor. Soc.*, **52**, 1926, p. 27.

INSECTS.—A17b, glow worm, March 6. B4a, late from wet autumn; 14a, scarce; so, as a rule, except most of C (not C11), specially many painted ladies (continental; clouded yellows, see below). 7a, no Tortrix damage to oaks; so passim. (E4i and F9d, full notes). G41c, many tortoiseshell early August, then butterflies scarce. J10a, Vanessidae from August. I38a, B. lapidarius nearly killed out in 1928 over pastures manured with phosphates, though not by basic slag.

The 1928 season was a notable clouded yellow year, both continental and native. It was reported from A1d (Land's End) to I10a (Lincolnshire, first for years). The former reports them from June 20 to October 21 in Scillies. Colias edusa and varieties and C. hyale are recorded. 15c, abundant all year to November 5; others to end October; C1f to November 6; C1j to mid-November; even well inland. D5e and 13c. They certainly gave a native summer brood.

Bees.—Disease is hardly referred to. June feeding was often needed, yet E10f records good honey harvest, but 38a, no heather honey from wet spell; so I24b (night cold). *Wasps* were generally scarce till late autumn. B42d, 51a, C4b "awful pest"; 6e, plums, apples, pears; C7a, 19 nests on 14 acres; 7c, worst known; 7f, "terrible, whole trees stripped of fruit, only left empty skins; 11d, worst since 1921, hence few white caterpillars; 15b, hundreds of nests taken, over 200 queens in one; D5d, yet aphis bad, countless nests taken; E10f; H18c; 138c, a record, took 46 "balls" and 19 "banks," one built round hedgehog skin; J6b; even K18b. Yet in places scarce. A27; D45a, not a nest; I26b, no queens seen, only one nest taken.

Pests.—Aoe, C22c, and others, woodlice. C3f, white admiral grubs on apple near oak wood; soft billed birds during dryness of June-August drought. 7f, specially aphis, magpie moths, gooseberry mildew, apple fungi, worst on leaves for 6 years; so plums, as if scorched, falling after midsummer. 20a, codlin moth. D13b, oak currant galls. 49c, no turnip fly. E1h, wingless moths on greasebands already by November 3. I33f, pests luxuriate. 38c, red spider; slugs a record (so C22c, etc.); hopes for good old-fashioned frosts; onion mould, onion and carrot fly, woodlice; weeds terrible, 9ft. roots of creeping thistle.

Summary.

Among the features stressed in our present Report, we may note the value of sub-district means, now given for A, F, H and D. An increase of 15 per cent. in stations above the previous record is gratifying. The weather vagaries justify the more detailed summary for short-period comparisons; so also the curious completeness with which the resulting phenological extremes in time and space cancel out for the whole year. The response by plants, birds and insects, each in its own way, to abnormal weather, especially to the cold snaps sandwiched into the mildness early on, was very marked. Yet, as they cover the whole period, the plant isakairs show but small divergence from normal,* while the sinuous zero line, stretching over fully 2,750 miles, exceeds any record in the previous 37 years. Our fresh Table IE, of coastal sea temperatures, brings to light a possible cause of uprushes in the plant and bird isophenes, especially in the Bristol Channel. Both in farm and garden the year was a decided improvement over 1927, save perhaps in the extreme north. But fruit again suffered from the late spring inclemency after the forcing effects earlier on.

On behalf of our Society we must again express its great indebtedness to the splendid and constantly growing corps of workers co-operating with the Committee.

ERRATA, 1927.

P. 222, Table II., 32c, for A. G. O. Marluas read A. G. O. Mathias.
P. 223, Table II., D17b, for E. H. Borough read Miss E. H. Borough.
P. 233, Table VI., 1927 No. of Stations, for "419" read "418," and mean of District F, for "42" read "142."

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* In reference to this we have received from the Russian Phenological Society an interesting criticism, based on our 1927 Report, on the consequent masking of real conditions only brought out by a division into sections, For this at present time is lacking.

DISCUSSION.

Sir **Richard Gregory**, D.Sc.: I am sure the Fellows would like to associate themselves with me in expressing appreciation to the authors of this report of the work involved in collecting and collating the vast number of observations included in it. Though some phenological observations are necessarily less precise than are, for example, readings of temperature, pressure or rainfall at specified hours, yet the maps of floral isophenes show clearly that the records in any particular district agree remarkably well with one another. Obviously the probable error in the date of a record must vary with the character of the occurrence recorded. Thus the dates of flowering of plants in the selected list may be regarded as almost as definite in the various districts as observations of temperature. Similarly, as the song of a bird can be heard over a fair area, it is likely to be recorded on the actual day. With the first appearance of insects the case is different. Turning to a district in Sussex and Hampshire, which I know fairly well, I find that the days on which the song thrush was heard at Havant, Chichester and Hayling Island respectively were 7, 3 and 5, the difference being, therefore, only 4 days. The dates of the first appearance of the humble bee in the same three places were recorded as days 63, 100 and 78 respectively, or a difference of 37 days. Evidently such records are liable to much larger probable errors than are dates of flowering of plants or of first songs of birds. The authors of this report are, of course, well aware of the relative weights to be attached to the various types of observation, but they cannot do otherwise than bring together the records actually received from observers. Our best thanks are due to Mr. Clark, Mr. Margary, Mr. Marshall and Captain Cave for carrying out this task so successfully.

Mr. L. C. W. **Bonacina** thought that the best interpretation of the isophenes could not be given without some index of moisture figures as well as temperature and sunshine. When the belated spring of 1929 would be discussed this time next year it could certainly not be put down to unduly cold or sunless weather. It was pretty obviously lack of rain during the early part of the spring that had held vegetation back, and even more the lack of snow over much of England during the hard winter. The lack of snow had rendered the soil unduly cold and dry, and only that very day an official agricultural report had appeared pointing out that in the west a deep snow cover had saved the winter wheat, whereas in the east and Midlands it had been practically destroyed by the frost, simply because of the absence of snow. Probably Rothamsted could offer advice as to how far the rainfall effect on the isophenes was retrospective, as the state of vegetation was not simply an expression of current rainfall. Mr. Bonacina also wished for information concerning reduction, or otherwise, of the isophenes to sea level in the backward mountainous regions of Wales, the Border, and the Highlands of Scotland. Stations in hilly country might easily differ in altitude by several hundred feet, which, according to the bio-climatic law, would mean a discrepancy of several days. If the isophenes were reduced to sea level and they still showed lateness it would prove, what is practically certain, that deep mountain valleys, whose floors are little above sea level, have a colder climate than the open plains. In winter deep mountain valleys are chilled by surrounding snows and by air drainage, and in summer by excess of cloud and rain, With regard to Sir Richard Gregory's reference to the song thrush, could it be said that the first song was definitely a spring event? Did not thrushes occasionally sing in autumn? He (Mr. Bonacina) would keep an eye, or rather an ear, on that matter in future.

Mr. MARGARY, in reply, agreed with the President that insect records were liable to be more erratic than plants, but added that the humble bee (included experimentally owing to bee disease) had proved particularly unsatisfactory and was no longer included in the schedule of observations. As it happened, the honey-bee records at these three stations were 53, 57 and 51, which showed quite good agreement. He thought it very unlikely that even loud-singing birds like the song thrush were recorded individually by more than one observer, for the observers were too far apart to be other than independent in all observations. With regard to Mr. Bonacina's suggestion it would be desirable to include the rainfall element in Fig. 2, but it was doubtful whether this could be done without making the figure too involved. Isohyets would hardly answer the purpose, differences from normal would really be needed.* The reduction of the floral isophenes to sea level had been tried some time before, but had not proved useful. The late areas in the Highlands, etc., still remained, and it was felt that the results hardly justified the loss of reality. He thought it ought to be considered whether more of the original records should not be included in the Report, long though it was already. At present only the district means for Tables IV, VIII, XII and XIII were printed, and in Table VIII in particular it was important that the original records should be available, otherwise much of the value of that series for correlation with foreign records would be lost.

Note on Phenological Effects of the Winter of 1929.

The Committee receives returns at the end of the year, so that only personal experience is available.

As in the two latest severe predecessors, 1895 and 1917, the preceding late autumn and December were specially mild, the frost period beginning in January. In 1895, at Street, Somerset, from December 21st to January 13th I recorded 99 wild and 106 garden flowers. Sweet violet, luxuriant dog mercury, whitlow grass with ripe seed, and a profusion of primroses were specially striking. In 1917, at Asgarth, Purley, the December garden total was 109, including 43 roses, but only 29 wild flowers were observed. 62 of the garden lasted into January, but only one other came into flower. Eleven lasted into February, when 12 more came out. Last autumn passed on decidedly fewer kinds; indeed, hardly any roses.

So much as background. Like those years the cold was a Continental invasion, the districts nearest the Continent being relatively most affected. Thus the deficiency in temperature in the second week of February was 14° in England N.E. and E., 14.7° in England S.E., 15.1° in the Midlands. Occasional short spells of warmth, sandwiched in, caused phenological responses; for instance, the bringing of snowdrop and hazel into bloom about February 9th.

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* It has been pointed out in more than one recent Report that the monthly isohyets and the percentage of the average for the whole year are available in the annual volumes of *British Rainfall*.

The almost entire absence of protective snow was a marked feature, total precipitation being far below normal, a condition accentuated in March and continued through April.

Having no protection plants suffered more than in 1917, though less than in 1895. Exotic conifers were seared; myrtle killed to the ground, and the majority of gorse bushes, wallflowers and antirrhinums perished in many parts. Greens of all kinds suffered seriously, such as broccoli and kale. Whole fields near Purley were ploughed up in consequence. The combination of frost and dryness, however, gave a splendid tilth in late March and April and good promise for farming.

The following table of flowers in bloom, in my very small suburban beds, gives the contrast with 1928, when December severity was followed by very mild spring conditions, almost uninterrupted until the cold spell in May. The data for 1929 are completed to the close of that month.

[Similar instances were also given from the bird and insect lists].

	FLOWERING EVENTS.					
	1928.			1929.		
	Total.	Fresh.	Aggregate.	Total.	Fresh.	Aggregate.
Dec. . .	19	5	—	29	5	—
January .	9	5	10	18	3	8
February .	31	22	32	14	4	12
March .	64	34	66	39	26	38
April . .	77	32	98	63	35	73
May . .	97	55	153	111	62	135

The "fresh" are those which came into bloom during the month. Hence the "aggregate" gives the actual number of the new season flowers at the end of each month.

As contrasts, consequent upon the different weather conditions, may be noted the larger number of December survivals last winter; the shifting of the month with fewest flowers to February; the total of only 7 fresh for January and February combined, compared with 27, giving aggregate of 12 only against 32; the March total in 1928 being nearly double, followed by rather more April and May fresh flowers in 1929 than 1928, though the aggregate at the end of May is less.

Taking flowers from Purley records of our phenological lists, Christmas rose, on December 27th, was 7 days earlier this spring; hazel 9 days later (February 9th); coltsfoot 35 days (March 20th); jack-by-the-hedge 35 (May 6th); hawthorn 21 (May 22nd); dog rose 14 (June 13th). Thus the lateness is being rapidly reduced.

J. Edmund Clark.

June 14th, 1929.

WEATHER AND WIRELESS

By R. A. WATSON WATT, B.Sc., F.Inst.P., A.M.I.E.E.

(The G. J. Symons Memorial Lecture, delivered on March 20, 1929.)

INTRODUCTION

I may be expected to offer some apologies before embarking on my main text, apology for violence done to the King's English, for treating wireless phenomena as belonging to meteorology, for devoting a Symons Memorial Lecture to a topic of which Symons scarcely dreamt. For the crime of treating an adjective as a substantive I plead two excuses, firstly that "Weather and Wireless" seems much less forbidding than "Meteorological Relations of Radiotelegraphy," secondly that the Imperial Wireless Conference was an accessory before the fact, although it put a timorous set of inverted commas around the new substantive "Wireless." Weather I take to be the ensemble of phenomena occurring essentially within the atmosphere, meteorology is certainly the science of things occurring "high in the air," and I have to talk of some things very high in the air indeed. As for Symons, I know you will eventually agree that only the accident of time prevented him from serving on the Atmospherics and Weather Committee of this Society.

WIRELESS AND WEATHER WARNINGS: PART I.

I must preface such limited references as I am to make to the subject of wireless communication as a tool of the forecaster by accepting as axioms (1) that the collection of synoptic data from wide areas is essential to forecasting, (2) that our weather comes mainly from the west, (3) that in the present state of our knowledge, forecasts for periods of 24 hours or less are alone possible, so that the greatest attainable speed in collection and redistribution of data is essential to usefulness, and (4) that in navigation the importance of meteorological data and forecasts subsequent to those available at the time of departure increases rapidly with the mobility, speed and range of action of the craft served, (5) that the fullest possible data are required by aircraft because of the extremely serious consequences of meteorological interference with normal flying. From these axioms emerge directly the corresponding conclusions as to the services to be rendered by radio communications to the practical meteorologist, in that (1) synoptic data for a whole country can be made available by wireless telegraphy within 1 hour, a sufficient representation for a continent within 1½, and for a whole hemisphere within 5 hours of the time of observation, (2) data from ships in the Atlantic, of special and indeed vital importance as containing first symptoms of impending changes, can only be received in time by the use of wireless telegraphy, (3) that the broadcast nature of wireless telegraphy is ideally suited for the rapid and economical interchange of data over wide areas, and (4) that aircraft generally, and long-range aircraft above all, are dependent on a wireless organisation for their effective action and for their safety.

It cannot be too strongly emphasised that the whole structure of a modern forecasting service rests on the foundation of an adequate wireless signal service, and that a heavy responsibility for safety of life thus falls on the signal service, a responsibility which can only be discharged by the utilisation of every new contribution to the science and art of radio communication and by a chronometer-like precision in the operation of the sensitive organism of the radiotelegraphic network.

On (1) and (2) I will confine myself to showing the chart for the northern hemisphere issued from the Meteorological Office at 11 a.m. to-day, containing 7 a.m. data from the Pacific coast of America across the Atlantic, Europe and Asia to the Pacific coast of Siberia, and to asking you to consider the difference in the forecaster's material when the land data shown in the chart for October 19th, 1928, was supplemented by timely data from the Atlantic shipping routes. The ships' reports show a deep depression off the west of Ireland. The indications of this depression on the land readings were very slight. The wind was SW. at Valentia, but it had been so at 1 a.m., so that this gave no clue, and the barometric tendency of −2 might have been due to some small irregularity of pressure which would have passed almost without effect on the weather. The reading from the "Majestic," however, showed that there had been a fall of 20 mb. pressure since 6 p.m. the preceding night over the Atlantic, and left no doubt that a major disturbance was approaching. By the evening of the 19th there were gales of force 8 and 9 on our south-western coasts. (3) is best illustrated by the increasing plumpness of M.O.252 "Weather Reports by Wireless Telegraphy," contrasting the first and the sixth editions.

From a mention of the essentially broadcast nature of radio communication it is natural to turn for a moment to that special section of wireless that has of late monopolised the term "broadcasting." Not the least of the incalculable services rendered by the finest broadcasting organisation in the world—our own—is the speedy dissemination of meteorological knowledge. Those of us who deplore the neglect of meteorological science in our schools and universities find comfort in the certainty that the British Broadcasting Corporation is educating a public opinion which will eventually remedy this neglect. It was a real joy to hear what befell an ex-president of this Society, casually suggesting to a roadman breaking stones in a Hampshire lane that "we might have snow." He was met with the reply, "Oh no, sir, we shan't have real snow with this anticyclone in charge. There is a small secondary depression producing the cloud, but beyond slight showers there is no chance of snow." The slogan, "Every home a local forecast centre," depends on the British Broadcasting Corporation for its realisation, and the transmission of synoptic charts is likely to be a new and important step towards success.

I am glad to be authorised to say that at an early date an experimental period of transmission of current synoptic charts will begin. The transmissions, which will be on the Fultograph system, will take place from Daventry 5XX, and it must be hoped that "listeners" will provide those responsible for the transmissions with sufficient data on which to base a decision on the usefulness of the experiment.

But, as I have indicated, the long-distance air navigator is the man whose success and whose life alike depend on accurate reporting and forecasting. The forecasters at the ground bases may do much for him, but for the balanced interpretation and utilisation of the forecast it is essential that he should examine the highly concentrated data contained in the synoptic chart. He must be meteorologist as well as navigator, and the ground organisation on which he depends must, in addition to sending him general inferences, forecasts, and further outlooks, place in his hands, in mid-air, at least the synoptic data required for the preparation of a weather chart, or preferably, on grounds of speedy assimilation, the chart itself. Wireless alone can reach him, but it must reach him with data hot from the observing network, and must be used in such a way that the labour expended on board in preparing it for use is reduced to an absolute minimum, in view of the other preoccupations of the personnel. Up to now the aeroplane pilot has had to be content with the limited information that can be conveyed in a short Morse message or a radiotelephonic message *en clair,* the airship navigator has had to draw his own synoptic chart from selected and limited cipher data transmitted at low hand speeds in Morse. Now, thanks to the development of practical and inexpensive picture telegraphy, we are justified in looking for

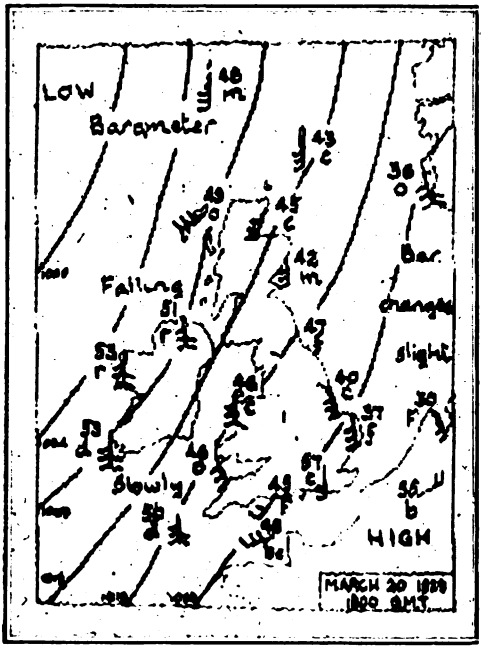
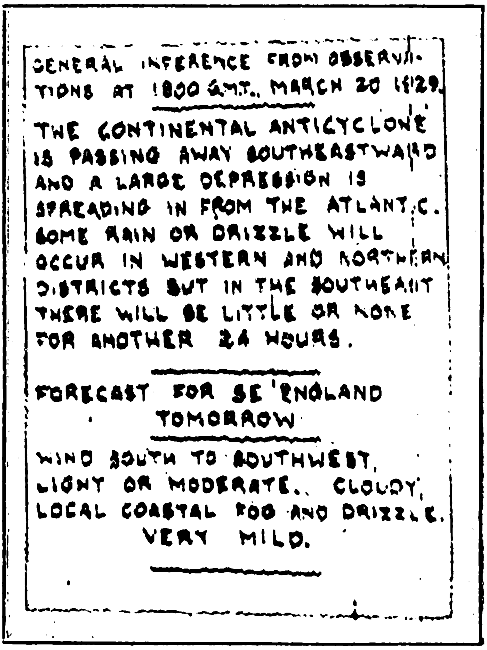


FIG. 1.—Synoptic chart transmitted and received by wireless on Mar. 20 by the Fultograph method.

an immediate revolution by which the air navigator will receive data and forecast matter written in plain script, transmitted at speeds of about fifty words per minute, and will moreover receive ready-drawn synoptic charts, drawn with all the facilities of a ground station and with all the accuracy and skill of a specialist in synoptic meteorology, on which he may without delay proceed to base his plans. By the very kind collaboration of several organisations I hope to show you now the reception of a synoptic chart (Fig. 1) and of a forecast (Fig. 2) all based on this evening's 6 p.m. data, prepared at the forecasting centre of the Meteorological Office at the Royal Airship Works, Cardington, which is charged specially with the provision of meteorological facilities for airships. The transmission by the Fultograph process is made from the wireless telephony station at the Royal Airship Works. In the interests of compression the chart now transmitted is sent from a photographic negative, but in the event of any system of facsimile transmission being adopted it is probable that speed and detail would best be served by the transmission of hand-drawn positives. Large areas could be dealt with by transmission in sections, these sections being ready for fitting together on reception into an open-scale synoptic chart, and supplemented by script messages also directly prepared by hand without the intervention of photography. I am glad to be able to show you also a synoptic chart actually received, by the Fultograph system, in an aeroplane flying over Austria.



GENERAL INFERENCE FROM OBSERVATIONS AT 1800 G.M.T., MARCH 20 1929.

THE CONTINENTAL ANTICYCLONE IS PASSING AWAY SOUTHEASTWARD AND A LARGE DEPRESSION IS SPREADING IN FROM THE ATLANTIC. SOME RAIN OR DRIZZLE WILL OCCUR IN WESTERN AND NORTHERN DISTRICTS BUT IN THE SOUTHEAST THERE WILL BE LITTLE OR NONE FOR ANOTHER 24 HOURS.

FORECAST FOR SE ENGLAND TOMORROW

WIND SOUTH TO SOUTHWEST, LIGHT OR MODERATE. CLOUDY, LOCAL COASTAL FOG AND DRIZZLE. VERY MILD.

Fig. 2.—Written weather forecast transmitted and received by wireless on Mar. 20 by the Fultograph method.

We must return towards the end of this lecture to applications of wireless to practical weather forecasting, but before that can be done we must consider the weather of wireless and the effects of weather on wireless.

THE WEATHER OF WIRELESS

The first attempts at wireless telegraphic communication revealed two great classes of phenomena limiting the range to which intelligible signals could be conveyed by artificially generated wireless waves. The first fact, not unexpected, was that signals became weaker as the distance between sender and receiver increased. As experiment proceeded it was found that the rate of attenuation with distance depended on many factors, type of intervening country, time of day, time of year, wave-length, and so on. Superimposed on these general attenuation phenomena, which we may call climatological in scope (if we treat wireless as being an activity with a kind of meteorology all its own), were found fluctuations of a rapid and apparently erratic character, suggesting weather rather than climatology. These "fading" phenomena, as they are called, are now playing an important part in the elucidation of many problems in radiotelegraphy and in atmospheric electricity. The second great limiting factor on signalling range was the prominence of spurious signals produced by naturally occurring electromagnetic waves, now called atmospherics. There is a climatology of atmospheric disturbance, since broad laws of incidence with time and season, latitude and topography, can be traced; their short-period changes are a part of wireless weather; in fact, atmospherics form the rainfall of wireless.

The history of civilisation is in the main the story of man's progress towards independence of the weather. New steps may for a time bring new phenomena under special consideration, but that is only part of the general advance in which originally prohibitive phenomena pass through a stage of being merely obstructive before relegation to the stages of inconvenience or harmlessness. And so wireless, having opened up new territory, is engaged in systematising its climatology, and in overcoming its weather. The history of these efforts would hold us too long; we must glance merely at a synopsis of the present position. Dealing first with wave propagation, it is now recognised that, in studying the variations of strength of wireless signals, we must consider, to a great extent separately, the energy which has travelled along close to the earth's surface and that which reaches the receiving aerial from higher levels. It will be convenient to apply the name "direct ray" to the bundle of energy reaching the receiver by the surface route, while energy coming by the upper routes forms "indirect rays."

Conditions favouring easy travel, *i.e.*, small attenuation, of the direct ray are sea routes as opposed to land, open country as against forest or towns. The direct ray is not very strongly affected by conditions of light or dark along its path. It is more severely attenuated if it is of short wave-length than if it is composed of relatively slow oscillations, *i.e.*, is of long wave-length. Its behaviour is amenable to calculation and close predetermination, and its sober demeanour makes it the only suitable medium for absolutely certain and systematic communication. The " service area " of a broadcasting station is that area within which the direct ray retains an energy level sufficiently high to give good signals in an average receiver. My colleague, Mr. R. H. Barfield, has prepared a map showing lines of equal signal strength round a broadcasting station, a map which shows the effects of towns and woodland areas in modifying the attenuation.

The indirect ray is a much more fickle and therefore a much more interesting element. The first essential is to inquire how it reaches the receiving station at all, since, as we have postulated, it reaches the receiver from upper levels. Since wireless waves are merely light waves of extremely great wave-length we may seek an optical analogy for this change in direction, and find it in the phenomena of reflection and refraction. Both these phenomena depend on a change of refractive index in the media traversed, a very steep gradient of refractive index gives reflection, a more gentle gradient, in a more or less layered structure, gives the refractions necessary to produce mirage. Now the effective refractive index of the atmosphere in the propagation of long electro-magnetic waves depends mainly on its content of ions,[1] charged particles either injected into it from elsewhere, or, more normally, produced within it by the separation of charges originally combined in electrically neutral molecules. So we conclude that the indirect ray reaches our receiver because it is returned from the upper air by a mirage effect, and that the study of the indirect ray, besides explaining the vagaries of wireless reception, may offer new and invaluable data on the ionisation in the upper atmosphere. The region of the atmosphere in which this mirage effect originates has been called the Heaviside layer, an admirable title which is defective in only two particulars, first that the ascription to Heaviside is inexact and second that the region is not a layer. It might be permissible to call it the Balfour - Stewart - Fitzgerald - Heaviside - Kennelly - Zenneck - Schuster - Eccles - Larmor - Appleton space, but something less indirect is desirable. I have suggested the name ionosphere to make a systematic group troposphere, stratosphere, ionosphere, but meanwhile the term " upper conducting layers " seems to hold the field.

The service area, as already mentioned, is characterised by the relative constancy of signal strength given by the direct ray. It might, at first glance, appear that it could be indefinitely extended by improvement in sensitivity of the " average receiver." But, in fact, irrespective of a wide range of variations in receiver sensitivity it is found that outside a very limited service area lies a wide region in which signals may be received feebly during daylight hours, but in which, once night has fallen, signals are sometimes very strong indeed; sometimes, on the other hand, they weaken to complete inaudibility, and violent alternations in strength may occur within a few minutes. Still further from the transmitter the signals may actually be less variable than within this zone of acute fading. The whole group of phenomena may be satisfactorily explained by postulating interference effects between the direct ray and one or more indirect rays; when the direct and indirect rays arrive by paths of such length as to reinforce one another at the receiver (the crest of a wave in the direct ray coinciding with a crest in the indirect ray) abnormally strong signals are heard; at times they will so completely neutralise one another (the crest of a wave in one ray filling the trough of a wave in the other) that the signal vanishes. The service area is that in which the direct ray is overwhelmingly stronger than the indirect; the zone of bad fading is that in which the direct and indirect rays are of comparable strength, so that opposition of phase can give almost complete neutralisation; while in the outer area the direct ray is much weaker than the indirect, so that the residual fading phenomena are due to modifications and interactions amongst the indirect rays themselves. The fluctuations of the indirect ray are to be ascribed to irregularities in the upper conducting layer, to varying ionic cloudiness, if we maintain our meteorological language. In view of the limitation of effective service area for the direct ray it will be seen that the greater part of the world's wireless communications is effected by indirect ray. In fact, we signal not by directing a wireless searchlight at the receiver, but by lighting up the electrical cloud layer with the searchlight, and letting the receiver read the lighting-up signals. This searchlight analogy is strictly accurate for a "beam" transmission, for "broadcast" transmissions the process is like that by which we in Slough infer the existence of London by night, from the diffuse illumination of a cloud layer by the broadcast lighting of the streets.

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[1] When the term " ion " appears in this discussion, it is used, in its general and original sense, to denote a charged mobile entity of size ranging from the sub-microscopic (electrons and molecular ions) to the just macroscopic (dust), irrespective of sign of charge.

That this explanation is substantially correct is best demonstrated by the beautiful experiments of Professor Appleton, in which, by the exact counterpart of familiar optical methods, he obtains photographic records of the interference fringes due to the interaction of the direct and indirect rays. I am glad to be able to show one of his records here (Fig. 3). By changing the frequency of the transmitted wave through a known small range, one obtains a number of fringes from which can be computed the effective height from which the indirect ray has been returned. This "effective height" is, in fact, somewhat higher than the highest level reached by the ray, since it is actually the height at which the directions of departure and arrival intersect.

From such measurements a most interesting mass of data has emerged. It is found that long waves return to us from heights of about 75 k., and the evidence fits with the assumption that they have undergone a process more resembling reflection in a rather poor mirror than refraction. The waves used in broadcasting are returned by a process of more gradual refraction, which involves their passage through a partly conducting region, for them the upper layers are a cloudy prism rather than a dirty mirror. The result is that while at night they return from heights of about 100k., in daylight they are so strongly absorbed in the refracting region that they return to the earth so weak as to be unobserved in normal reception. Hence the extreme difference between the

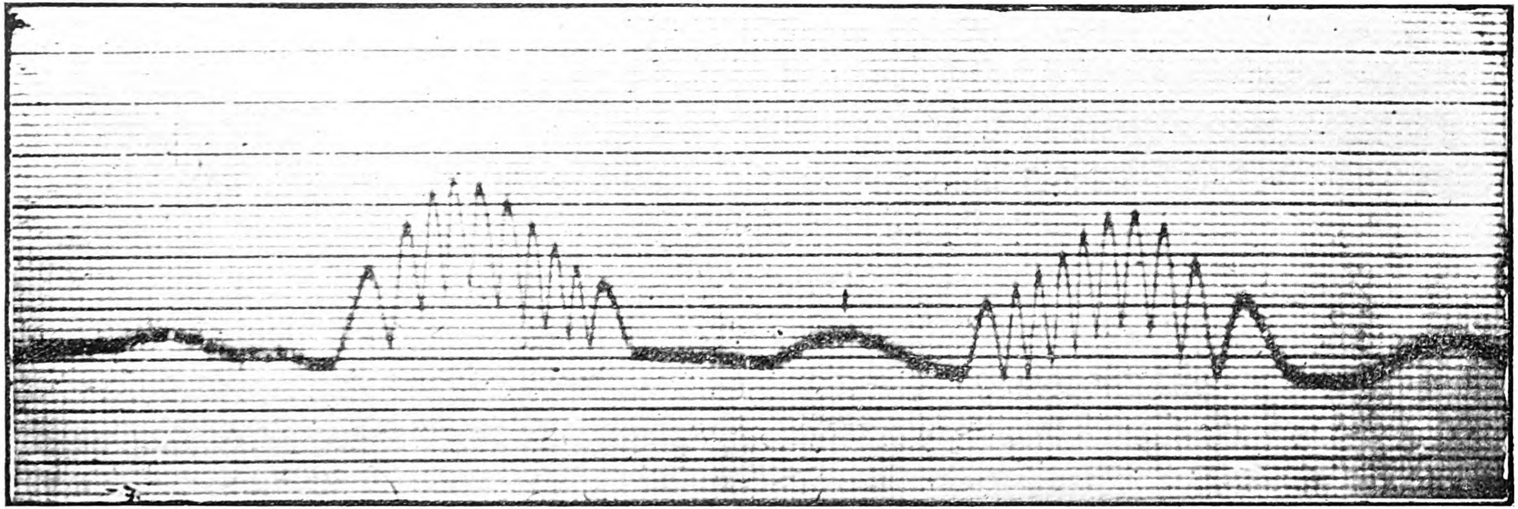


FIG. 3.—Fringes produced by changing transmitted wave-lengths in conditions where interference between "direct" and "indirect" rays occurs.

number of broadcasting stations to be heard before and after dark on the ordinary receiving set. The shorter the wave-lengths the greater the number of ions per unit volume required to return them towards the ground. Thus, with the waves of the broadcast band, a hundred thousand electrons per cubic centimetre are required, and this density will, at night, be found at about 100k. height. Towards the end of the dark period, recombination of the ions produced in the preceding day will reduce the concentration, in which case the effective height of this layer will increase somewhat; then the concentration may fall so low that there is, effectively, a hole in the 100k. layer, and the waves then proceed to a height of about 220k. before they find sufficient electrons to turn them back earthward. Our present picture of the structure of the atmosphere is thus somewhat as in the diagram (Fig. 4). The general effect of increasing solar activity, whether considered over the eleven-year cycle or in cases of individual disturbances, is to increase the ionic concentration in the ionosphere, thus improving the reflecting power of its boundary for long waves, and favouring the transmission of such waves over long distances, but increasing the absorbing power of the regions penetrated by short waves, and thus impairing short-wave communication.

It is fair to assume that with a wide enough range of transmitted wave-lengths it will in future be possible to measure the heights at which selected ionic densities occur, so that the geophysicist at ground level can shoot an arrow into the air and bring down data as to the gradient of ionisation up to heights of hundreds of kilometres. It is not improbable that such soundings will give more detailed information as to the constitution of the atmosphere at great heights than will any other methods, as Pedersen, in his daring book on "The Propagation of Radio Waves," has recently argued.

One of the awkward results of the comparative ease with which short waves can travel by this overhead route is the reception of wireless "echoes." In transatlantic short-wave signalling, for example, it may be found that for one dot transmitted two are received, because one set of waves from the transmitter has been received from the east while another set has come in from the west after travelling round the remaining portion of the earth's transmitter with no back-end radiation and a receiver blind to signals it is no exaggeration to say that so-called "beam" transmitting and receiving systems are more important from the point of view of minimising signals travelling "the wrong way round" than from the point of view of economy in power. This type of difficulty would not, however, be completely eliminated even by a transmitter with no back-end radiation and a receiver blind to signals from the rear, because it is still possible to receive signals which, having passed the receiver, have been once, twice or thrice around the world and still arrive by the front door at sufficient strength to be comparable with the first arrival. The diagram (Fig. 5) shows records of such signals. It would be arbitrary to expect the mechanism which makes it so surprisingly easy to hear low-power signals from the Antipodes to be so finely adjusted as to leave them strong over a path of one semi-circumference of the

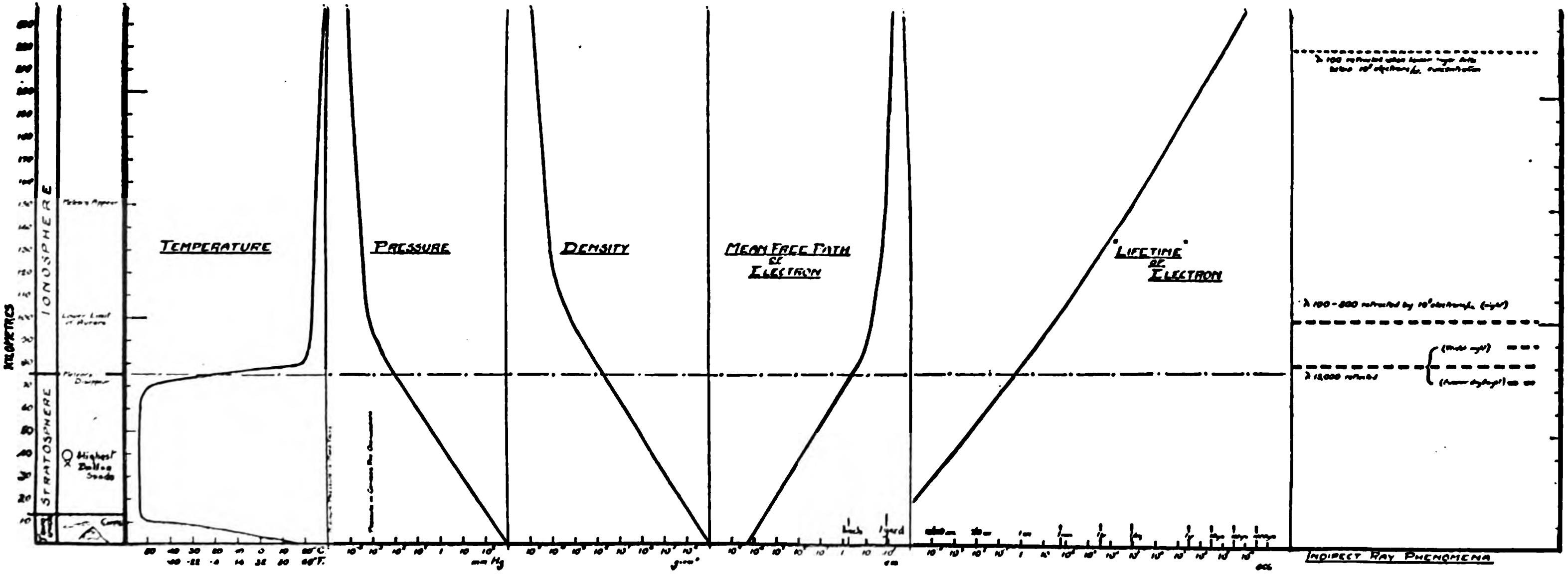


FIG. 4.—Approximate distribution in height of temperature, pressure and other elements.

[The diagram is very crudely representative of the orders of magnitude at various altitudes of the physical quantities shown. The available data are inadequate for close representation of conditions above 20k. and no care has been taken to make these curves consistent one with another.]

(Modified from Pedersen "Propagation of Waves.")

earth and to extinguish them before three semi-circumferences had been traversed.

In leaving this aspect of wireless weather, I must briefly mention the disturbing observations of Störmer and his collaborators on an echo which, instead of arriving one, two or three sevenths of a second late, as is the case with the echoes I have just shown you, linger somewhere for periods of one to thirty seconds before entering the receiver. If they have travelled with the conventional velocity of 3×10^{10}cm/sec. the waves giving this echo must have been out beyond the moon, and the problem then posed is to account for their finding out there a sufficient ionic density to return them to earth, particularly as they had not been completely turned back by the gradient through which they had to pass on outward and inward journeys through the ionosphere. Störmer points out that the experimental facts agree with his 25-year-old postulate of a girdle of ions about the earth, in the form of a torus generated by the revolution about the earth's magnetic axis of an oval, tangential to that axis at the centre of the earth. He showed that electrons discharged from the sun would form such a torus under the action of the earth's magnetic field, and Birkeland photographed the distribution in the course of his beautiful experiments with cathode rays bombarding a terrella. Störmer's argument that the long-delayed echoes are due to reflection from the earthward surface of this girdle, despite the difficulties of accounting for the high electron density, is enormously reinforced by that prime test of all hypotheses, the power of prediction. The most favourable configuration for reflection occurs with the sun in the plane of the earth's magnetic equator; the echoes in question were first measured in October, 1928, when this configuration occurred, then they were lost, but Professor Appleton has been so good as to allow me to refer to the unpublished fact that he has just observed these echoes again, at the time at which Störmer predicted their reappearance.

If we reject the Störmer hypothesis we are involved in competing hypotheses on one of which the signals linger in regions where their group velocity is very low, and in which they must inevitably be very highly absorbed; on another the random fluctuations of the ionosphere produce strong concentrations of signal energy at the required long intervals. It must be confessed that the frequency curve of delay intervals, showing some delays of 25 to 30 secs., but with a most frequently occurring delay of 8 secs. and other peaks at 5 and 12 secs. is not satisfactorily dealt with by any of these three hypotheses in their present state of development, and further observational material is essential.

Turning to atmospherics one must first say that not all the noises commonly called atmospherics deserve the name. There is a far from negligible tendency to apply the name indiscriminately to all interfering noises in radio reception. It should, of course, be restricted to such noises as are definitely not artificially produced, as by tramways, medical apparatus, lifts, oscillating receivers, lighting switches, transmitter "mush," etc. A number of general facts about true atmospherics had been amassed during the early history of radiotelegraphy. They are more prominent on long

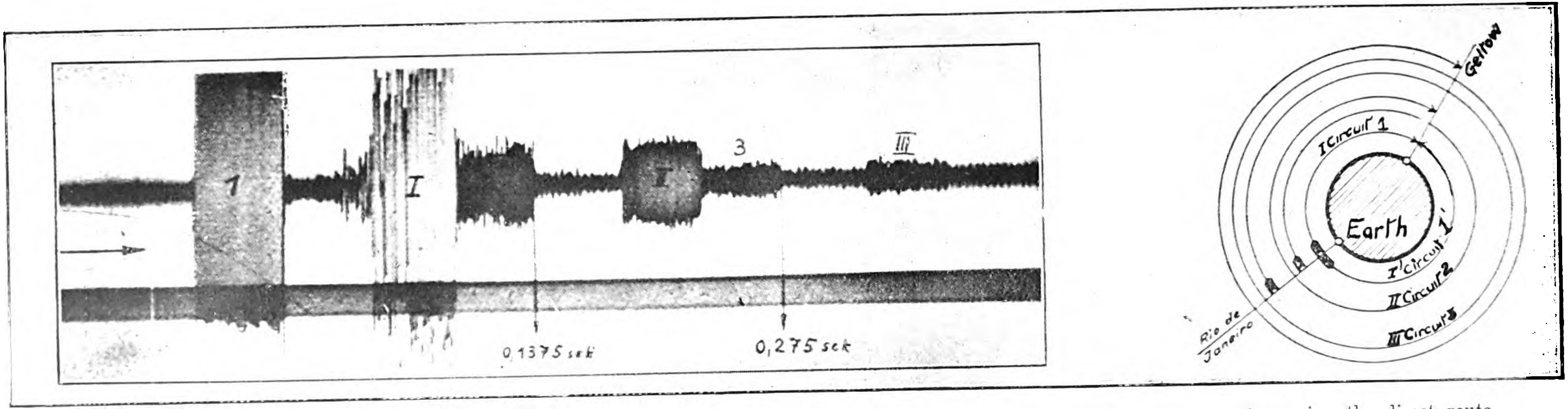


FIG. 5.—Oscillographic records of short-wave signals which have travelled once and **twice round** the earth in addition to traversing the direct route.

(From Quäck. Jahr. D.T. 30 Aug. 1927)

To face page 284.

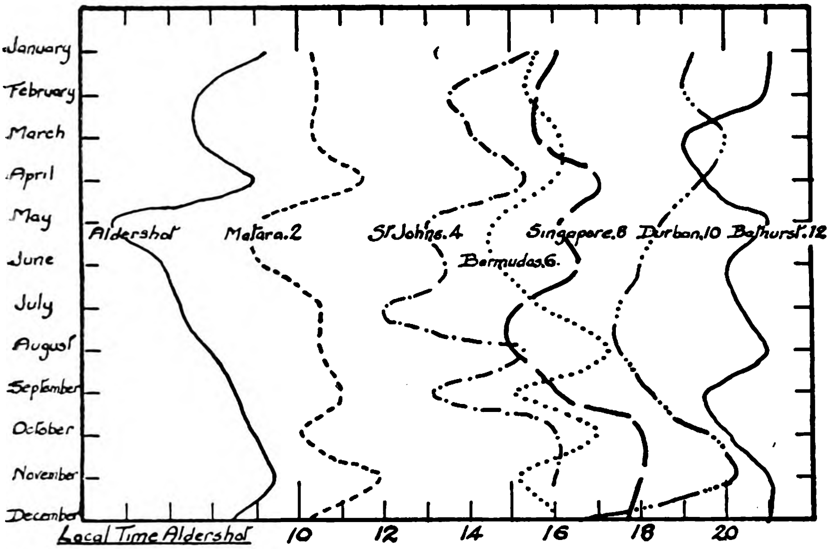
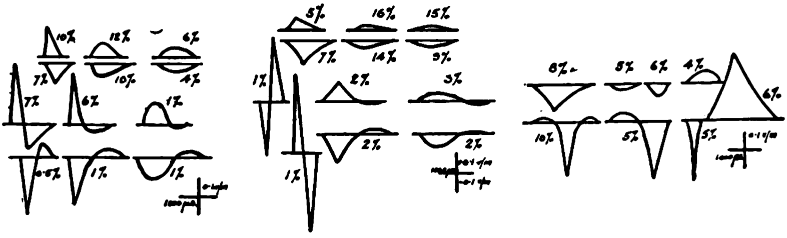


FIG. 7.—Monthly variation of hour of minimum disturbance. Time scale for Aldershot as shown; for other stations subtract small numeral appearing after the station's name to obtain local time scale. The displacements along the time scale are purely arbitrary, to separate the curves.

disturbances reaches any station. This has been recorded continuously at various stations in recent years. If the average monthly direction of arrival at all stations is plotted for each hour of the day, the march of the apparent predominant source across the earth can be traced.

The shape of atmospherics can be investigated by a comparatively simple method by which many thousands of pictures of individual atmospherics have been drawn. The general result of these investigations is that the average atmospheric applies to the receiving aerial an electric force nearly a hundred thousand times as strong as is required to produce a readable signal, but that the duration of the applied force is only a few thousandths of a second. Some typical home and tropical atmospherics are shown in Fig. 8.



Sudan. SE. England. W. Australia.

FIG. 8.—Scale drawings of main types of atmospherics seen at different stations, with their percentage frequency of occurrence.

The distance from their places of origin at which atmospherics may produce disturbance in ordinary receivers has been examined by several workers, including a committee of this Society. The committee's work showed conclusively that broadcast reception might frequently be disturbed by atmospherics radiated from centres 4,000 miles away.

It has also been found possible to count atmospherics, even when their rate of incidence is very high indeed. By spreading out the events of a tenth of a second over a kind of venetian-blind pattern in which each lath is a hundredth of a second one can determine that in England measurable atmospherics come in at the rate of about 50 per second at night, while in the tropics the numbers are of the order of 50 per second by day and a few hundred, rising occasionally to a few thousand, per second at night.

Moreover it can be found that the number of atmospherics per unit time, N, which pass selected limits of strength, E, is expressed approximately by a law $NE^2=K$. This law is of importance as indicating that reduction of power at the transmitter cannot to any useful extent be compensated by increase of amplification at the receiver, since the relative noise level due to atmospherics rises very steeply as the signal strength is decreased.

The Effect of Weather on Wireless.

The first detected effects on radio communications of the phenomena generally called weather were the disturbing effects of atmospherics radiated from visible lightning flashes. In fact, as is well known, radio receivers were applied by Popoff, of Kronstadt, as thunderstorm detectors before radio communication by artificially generated waves began. There is not yet substantial agreement amongst geophysicists on the question of whether all atmospherics proceed from discharges which the meteorologist would call lightning, although I must say at once that I know at present of no evidence which I can accept as valid in opposition to a hypothesis of this general nature. A brief survey of some of the available evidence may indicate our present position. Cave and I showed that many of the apparent sources of atmospherics located by radio-telegraphic direction-finding coincided with observed thunderstorms. On fuller examination of the same data I found that such agreement with reported thunderstorms was somewhat rare, that, in fact, only 25 per cent. of our sources of atmospherics fell near places from which thunderstorms were reported, but that almost all fell in places of meteorological disturbance. Captain Bureau, of Paris, has cast doubts on the credibility of the results by remarking that none of our sources are located in tropical Africa, which he regards as a favourite hypothetical factor for atmospherics in English theory. The answer to this is implicit in the original publication, it is that such sources were trigonometrically ill-situated for location by British stations. Colonel Sacco, of Rome, has made a criticism which at first sight is more damaging. He shows that, with the accuracy of observation specified by us, the statistical distribution of bearings shown by us would yield " chance " intersections of three, four, five and six bearings almost exactly equal in number to those actually observed. He suggests, then, that the locations obtained may be merely " chance " ones. This argument assumes that the mean directions and standard deviations in question result from sources independent of those apparently located. In fact, however, the agreement between the "probability" numbers and the "observed" numbers of n-bearing intersections constitutes a demonstration that the sources located are fairly representative samples of that distribution of sources which controls the observed distribution of bearings, and thence that the meteorological situation of Europe and Northern Africa is the predominant controlling factor in the atmospheric disturbance on medium wave-lengths in Great Britain.

On a wider scale, as I have already noted, we have located apparent sources of atmospherics all over the world by a network of directional recorders. The mean apparent sources at each hour of the average day of each month are shown in the "war map" already mentioned. The colour scheme makes it clear that in general atmospherics originate in a local summer afternoon or evening on land, as they must do on the theory of convective thunderstorm origin. The unfortunate African thunderstorms, alleged to be specially dear to the heart of the English school of thought, again fail to find a place on the map because for a mainly European observing network their effects are overlaid by the European thunderstorms occurring at the same time, because on the same meridian.

On a still more strictly quantitative basis rests other evidence of the relation between the average atmospheric and the average lightning flash. Professor C. T. R. Wilson measured the quantity of electricity discharged in English lightning flashes. Now it is readily shown that the shape of atmospherics, (cf. Fig. 8) as delineated by an eye-and-hand method corresponds to the second time-differential curve of the destructive process radiating them. We can then infer, by a graphical integration of the wave form of an atmospheric believed to proceed from a lightning flash at an approximately known distance, the quantity of electricity destroyed in producing it. For various moderate to long distances this is found to agree with remarkable closeness with Wilson's measurement at short distances. Moreover the average atmospheric received in England is of just the right strength to have been radiated from a lightning flash 2,000 miles away, *i.e.*, from regions in which thunderstorms are frequent. Again, the numbers of atmospherics per unit time as counted by methods already mentioned, are of the right order to fit with Brooks's estimate of the average total number of lightning flashes, 100 per second, occurring over the earth's surface as a whole.

Much greater precision in our knowledge of such problems is to be expected when our methods of locating the places of origin of atmospherics are improved. An apparatus (Fig. 9), demonstrated in operation after the lecture, and which is now in use in Great Britain and in America, is a visual direction-finder which, by itself drawing a luminous line on a compass dial, shows the direction along which an atmospheric, although lasting only a few thousandths of a second in all, reached the observing station. Using two such instruments, one in Scotland and one in England, with telephonic communication between observers, we have been able to plot the approximate places of origin of individual atmospherics. An average summer day is represented in Fig. 10, and it will be seen that the areas of reported thunder and those of maximum production of atmospherics are in substantial agreement.

This historical examination of agreement with reported thunderstorm phenomena is, of course, only of value in so far as it points the way to the far more important possibility of agreement between observed atmospherics and unreported or impending instability phenomena. I have shown elsewhere how our recording network tracked one cold front across Europe, another over the Mediterranean, while Fig. 11 shows suggestive concentrations of sources of atmospherics in the neighbourhood of frontal phenomena.

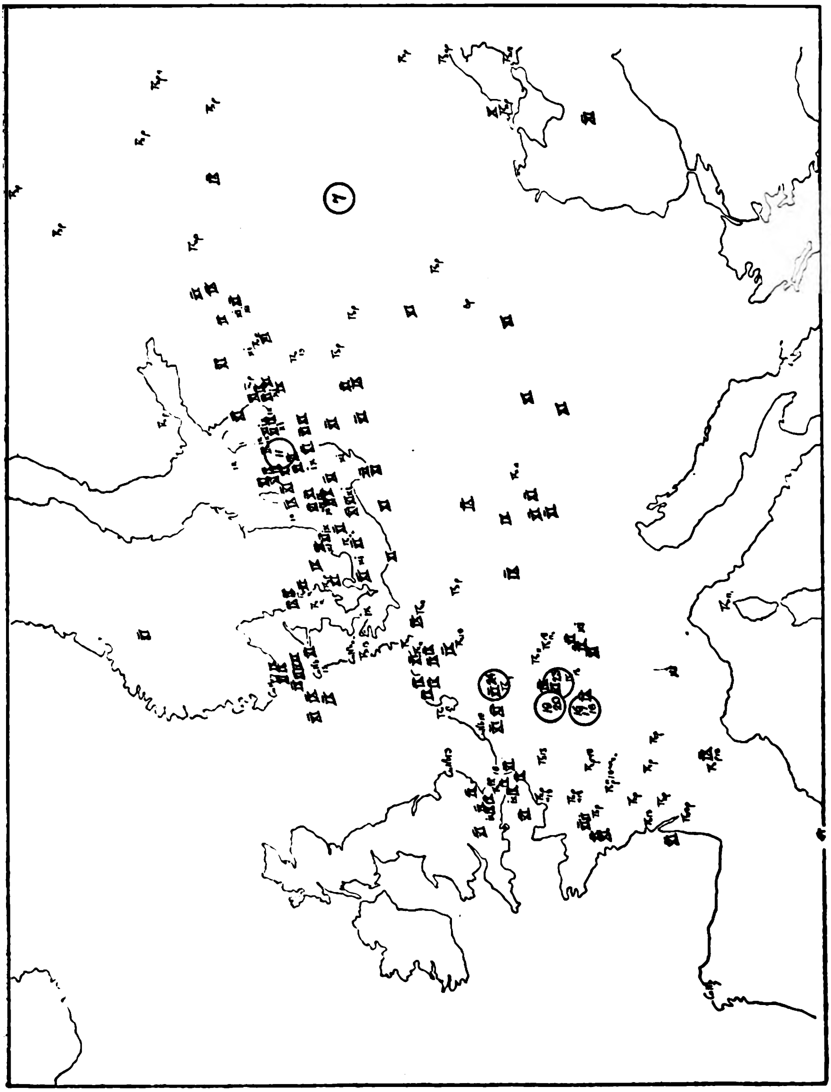


FIG. 10.—Atmospheric sources on July 6th, 1927. Those located by Cathode Ray Direction-Finder shown by Roman numeral, indicating time intersection was obtained; by continuous Frame Recorder, an Arabic numeral in a circle. Thunderstorm data plotted from Daily Weather Reports.

Some of the range experiments already referred to showed close agreement between frontal positions and the sources of individual atmospherics which disturbed reception some thousands of miles away (Figs. 12, 13, 14).

None of the experiments to which I have referred have suggested any appreciable percentage of sources close to any one observing station, such as might have been expected to be found if the alternative hypothesis, that the majority of atmospherics are of short range, were true. This alternative hypothesis has been put forward both in Germany and in France, and we must review the evidence briefly, although we shall find that no really crucial experiment has been carried out by those holding this "back-

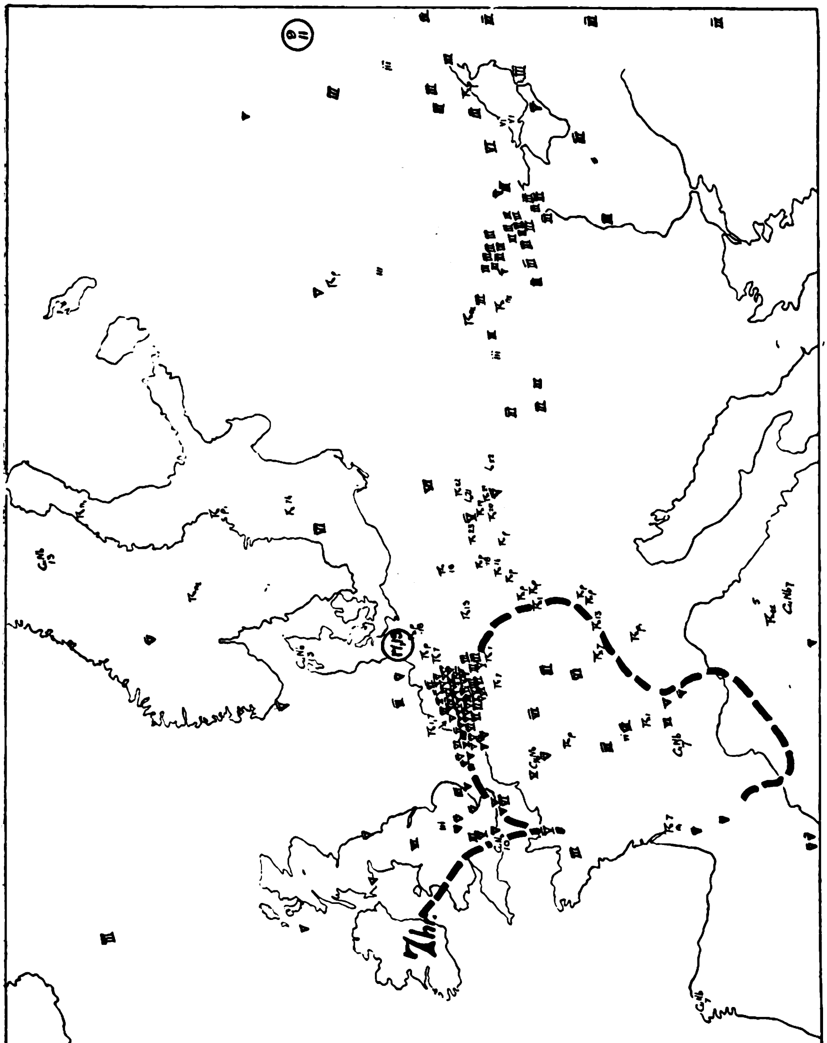


FIG. 11.—Atmospheric sources on July 1st, 1927. Position of Polar Front at 0700 shown.

garden " view, to set against the evidence for predominantly long ranges.

Herath studied the currents flowing in a kite wire during aerological ascents at Lindenberg. He found that the current had a relatively steady rate of increase as the kite ascended in a homogeneous air mass, but that sudden and violent changes in current value occurred when the boundary between two air masses was crossed, the boundary being normally marked by an inversion of temperature gradient. When the kite had ascended beyond the interface the current curve became steady again. He observed that the sudden changes in current coincided in time with rustling sounds in a neighbouring wireless receiver, sounds which did not alter in strength or number when the kite wire was reeled in. He infers from this and cognate observations that the majority of atmospherics received at any station originate at discontinuities in the atmosphere near the receiver. Bureau has studied the losses of text words caused by atmospherics disturbing actual received messages, and concludes that atmospherics are radiated from discontinuities, but are not in general received at more than a hundred kilometres or so from their source. One of the bases on which he rests his estimate of extremely restricted ranges is a comparison between records of atmospherics and of wind at the same station. He finds agreement between peaks on the record of

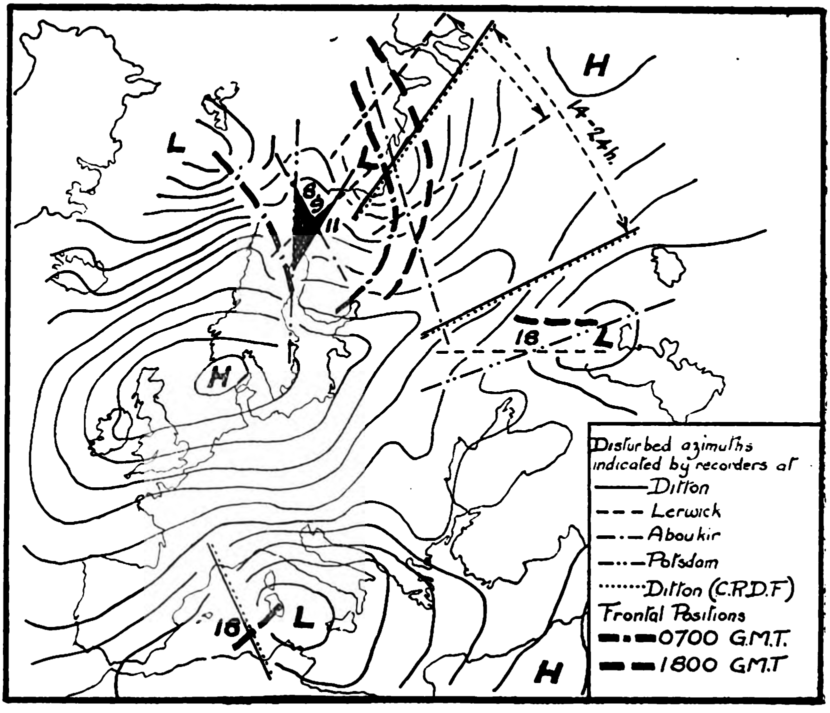


FIG. 12.—Sources of atmospherics in Mediterranean and in U.S.S.R. located by direction finding.

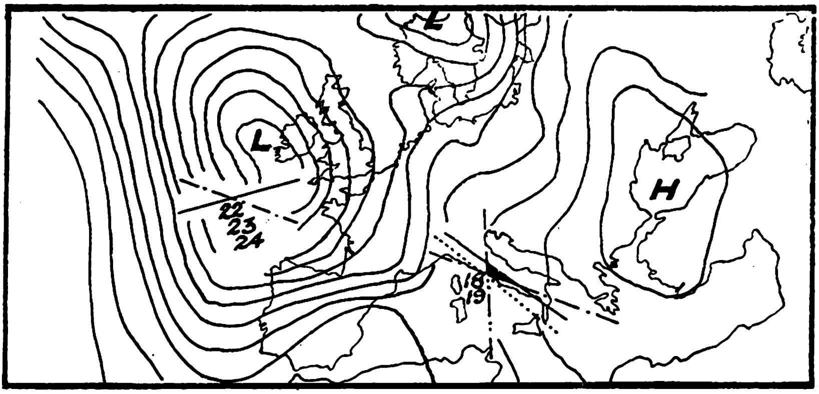


FIG. 13.—Sources of atmospherics near Rome and in the Bay of Biscay

atmospherics and marked features of the anemogram. But that this is not the whole of the story is shown by the fact that the agreement between peaks on the simultaneous records of atmospherics at Paris and Slough is much closer than the agreement between Paris atmospherics and Paris wind.

This is one of the many points awaiting elucidation by concerted observations; in this connection, and in reference to a remark by Dr. Whipple in a recent discussion, it is gratifying to be able to report that a large-scale international investigation of atmospherics has now been launched. Thanks to the generosity of a great American organisation, recorders, of a type first used in this country, will be installed throughout the world for the collection of homogeneous data from identical apparatus.

I do not think the time has come for any general summing up on the origin of atmospherics, but I will say that all the evidence available to me leads me to the following interim beliefs. The

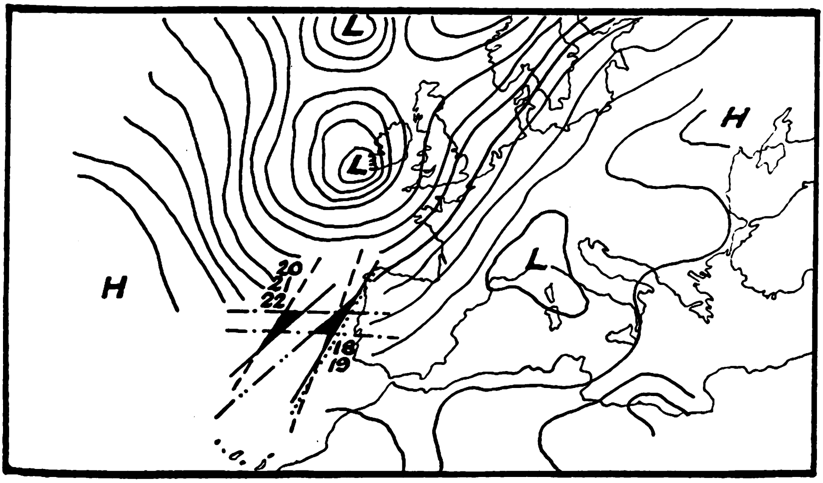


FIG. 14.—Sources of atmospherics off Portuguese Coast.

great sources of the world's supply of atmospherics lie in the great thunderstorm areas. The great majority of the atmospherics, exceeding a few millivolts per metre, at any point in temperate latitudes come from considerable or great distances. There is no convincing evidence against the hypothesis of a terrestrial meteorological origin for all atmospherics. If I am asked to be more definite about "meteorological origin" I will go so far as to say that I believe all atmospherics to originate in discharges of the same nature as lightning, although possibly no very large percentage of the discharges may reach or be visible from the ground. It would take me too long to say here why I disagree with Schindelhauer's views as to the origin of atmospherics, but I hope to give reasons at length in another place.

Indeterminate as is the situation in respect of the particular "weather on wireless" effects just discussed, it is crystalline compared with that next to be mentioned. In 1902 Captain (now Admiral of the Fleet Sir) Henry Jackson, in a paper which laid the foundations of our knowledge of the relations between weather and wireless, gave evidence of the relations between atmospherics and depressions, and then proceeded to discuss variations in wireless signal strength associated with weather changes in the Mediterranean. Nearly thirty years later we have added sadly little to the evidence in either group of phenomena. He reported, "The next cause which is ultimately connected with the above is the shorter distance at which signals can usually be received, when any electrical disturbances are present in the atmosphere, compared to the distance at which they can be received when none are present. The distance varies from about 30 to 80 per cent. compared with that obtained in fine clear weather. It does not in any way decrease with the increase of the number of lightning discharges which register their effect on the instruments, at any given time, but rather the reverse, the loss in distance generally preceding the first indications, on the instruments, of the approaching electrical disturbance.

"A very marked case is given as an example: Two ships whose instruments were in perfect order, and whose sea-signalling distance was about 65 miles, opened their distance from each other on a fine, calm, bright day; when they were 22 miles apart the signals died away, though there was no intervening land or other apparent cause for this, but it was noticed that the barometer was falling; the ships closed and got into communication again. Atmospheric disturbances were then registered on both sets of instruments, and on the ships opening out again, no signals were obtained over 20 miles. The trials were concluded shortly after, owing to intervening land. A few hours later a heavy winter gale came on, and its approach had evidently been foretold by the falling barometer, the loss of distance in signalling, and the electrical disturbances in the atmosphere, as shown by the signals received on the instruments. No lightning flashes were observed.

"On another occasion, during a period of strong but intermittent atmospheric effects, no signals were obtainable between two ships up to the usual maximum signal distance. When separated 50 per cent. beyond this distance, and immediately after a particularly strong and persistent series of electrical discharges, the latter half of a signal, which was being transmitted very slowly, was correctly deciphered at a distance then considered phenomenal, with the instruments employed at the time. A few minutes later the atmospheric effects vanished, and with them all signs of further signals, till the ships had closed to their usual signalling distance. This demonstrates that the actual electrical discharges do not of themselves reduce the signalling distance or transmission of the waves at all times, but that they may, in some circumstances, assist that transmission, possibly by a cumulative effect of the waves emitted by the discharges on the waves emitted by the transmitter, these combining and increasing the effect in the receiver.

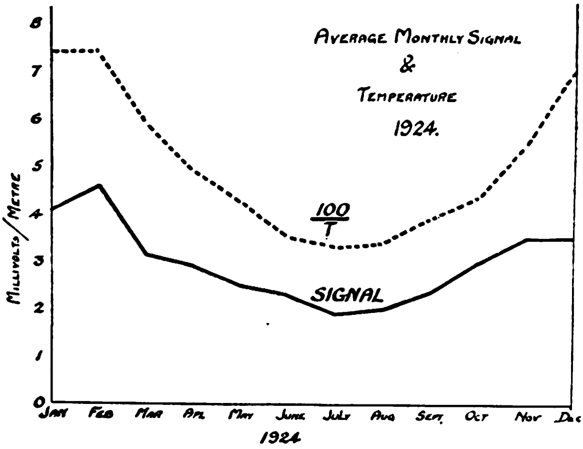


FIG. 15.

"Another observed effect which reduces the usual signalling distance is probably due to the presence of material particles held in suspension by the water spherules in a moist atmosphere.

"The Mediterranean Sea is, for days together, frequently exposed to the force of the sirocco wind; this South-easterly wind is laden with damp, and often charged with salt from spray, and dust particles from the African coast. During the continuance of these winds, the maximum signal distance is generally less than in winds (wet or dry) from any other quarter, the proportional distance being from about 60 to 80 per cent. The effect of a sirocco wind can be and is allowed for in practical wireless telegraphy."

Austin has shown that long-wave signals over distances of about 300k. are weak when the air temperature along their path is high, as shown in Fig. 15. It would seem probable, in view of the wave-lengths involved, that the direct ray is mainly concerned. In this case the strong temperature term in the law of attenuation is sufficiently surprising, but the assumption that the indirect ray is affected by phenomena far above the troposphere yet intimately related to ground temperatures is even more far-reaching in its implications. Once more we may look forward to new light on geophysical relationships from a following-up of this work.

The observations of the Lindenberg school on aerological reactions on radio-wave propagation are of very great interest. Herath has examined the meteorological situations over the path of signals whose day-to-day variations in intensity were studied by the Telegraphentechnischen Reichsamt. The three cases shown in Figs. 16, 17 and 18 speak for themselves as illustrating Herath's conclusions that:—

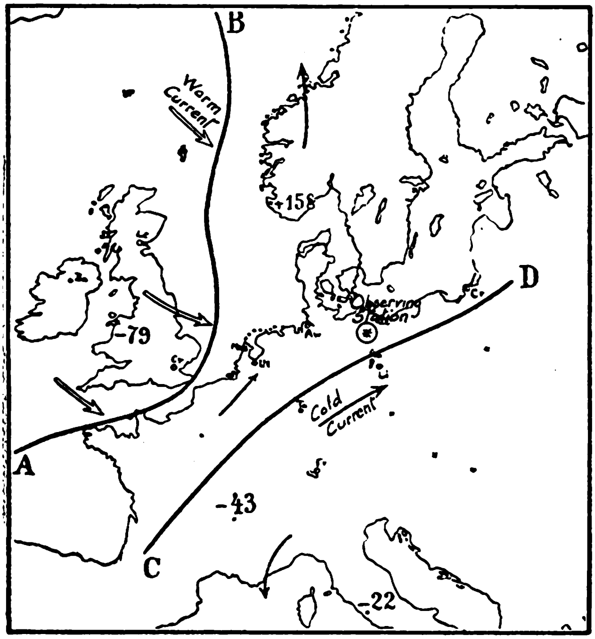


FIG. 16.—Effect of discontinuity surfaces on signal strength.

[Numerals represent the percentage increase or decrease in received intensity at Strelitz-Alt of the transmission from the Station covered by the numerals.]

22nd December, 1920.

(1) Surfaces of discontinuity between sender and receiver diminish the received energy.

(2) Surfaces of discontinuity over the sender increase the received energy.

Duckert has carried this matter further by making measurements of received signals, over comparatively short distances, during the passage of marked meteorological discontinuities over his receiving station at Lindenberg. The three examples shown (Figs. 19, 20 and 21) illustrate his main conclusion that reception along a path coinciding with the axis of an occlusion is exceptionally bad. Duckert states his conclusions as under:—

1. Every warm mass of air passing over the receiving station impairs the reception of wireless signals for considerable periods (of the order of ten minutes); the passage of the trough is particularly marked.
2. The effect is especially clearly important if the longitudinal axis of this " occlusion " coincides in whole or part with the direction transmitter-to-receiver.
3. The more extensive the agreement in direction, the more intense and persistent is the weakening of the signals.

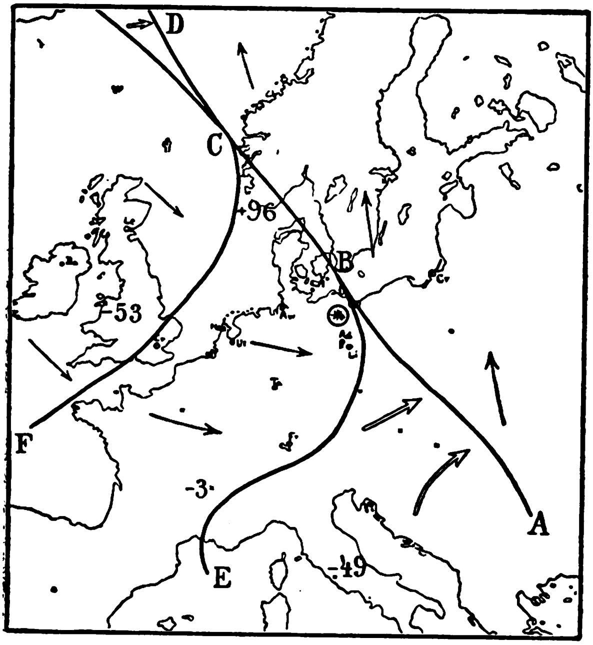


FIG. 17.—Effect of discontinuity surfaces on signal strength.

[Numerals represent the percentage increase or decrease in received intensity at Strelitz-Alt of the transmission from the Station covered by the numerals.]

11th January, 1921.

4. The impairment of reception in the case of an occlusion is specially notable when the absolute humidity falls off rapidly with height.
5. If the trough of the elevated warm mass of air lies at right angles to the direction of reception, a short-period effect is experienced, either strengthening or weakening of the signals, according to whether the lowest portions of the occlusion lie near the transmitter or near the receiver.
6. The wave-length has a considerable influence on the effect, the shorter waves being notably more readily affected.

Special emphasis is thus laid on the gradient of absolute humidity with height as a determining factor in the effect on wave propagation of surfaces of discontinuity. These propositions offer the prospects firstly of a rich field of investigation in geophysical relationships and secondly of a possible addition to the tool-chest of the synoptic meteorologist.

It will be noticed that I have implicitly regarded meteorological influences on signal intensities as residing in the medium and not as originating in the transmitting or receiving antennas. This is justified by definite measurements, due to Esau and others, showing that it is only in exceptional circumstances, as for example, in a glazed frost, that the direct meteorological effects on the antenna assume magnitudes comparable with those discussed here. Secondary phenomena, such as variations of signals from Spain received in Germany, giving low values when the snow on the Pyrenees is melting, have also been reported.

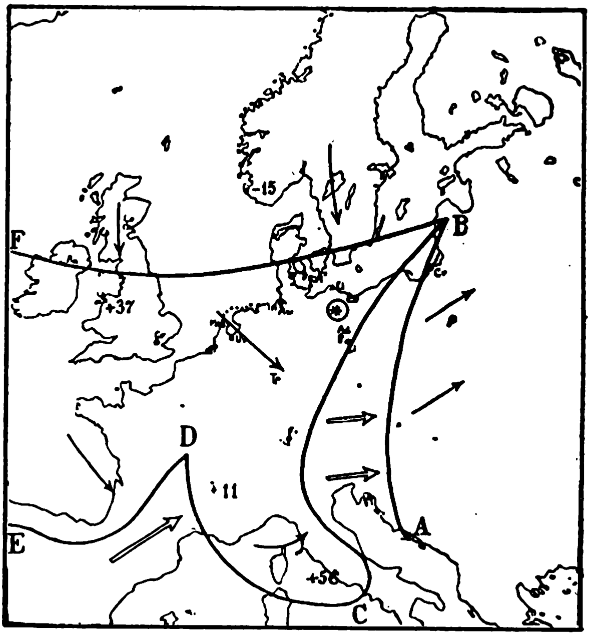


FIG. 18.—Effect of discontinuity surfaces on signal strength.

[Numerals represent the percentage increase or decrease in received intensity at Strelitz-Alt of the transmission from the Station covered by the numerals.]

27th January, 1921.

Duckert has explored another avenue of approach to the elucidation of aerological influences on wave propagation. He has examined a series of direction-finding measurements on wave-lengths of 300 to 2,000 metres, over distances of the order of 50 to 300 nautical miles, so that one would assume that the direct ray is of greatly predominant importance in the measurements. In a special series of experiments over ranges between 60 and 75 nautical miles, reciprocal bearings were taken between ship and shore stations, *i.e.*, a direction-finder on shore found the apparent bearing of the ship transmitter, while a direction-finder

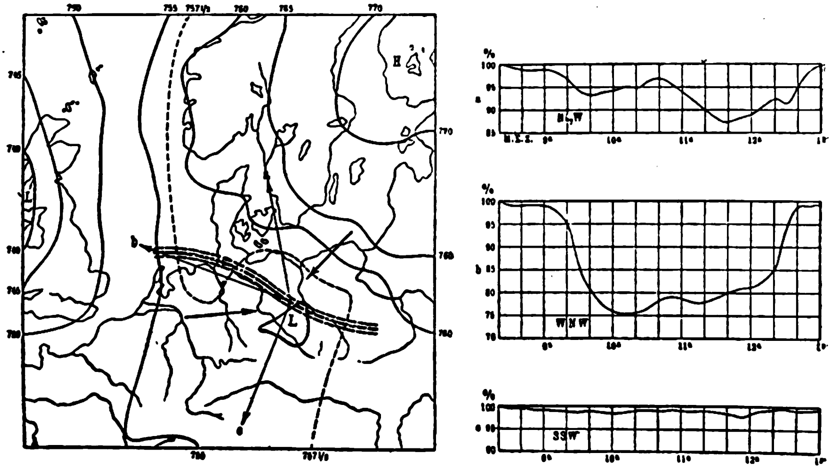


FIG. 19.—Curves of Relative Signal Strength against time, along various paths, showing diminution of signal strength along axis of occlusion.
23rd February, 1925.

on the ship made a sensibly simultaneous determination of the apparent bearing of the transmitter situated at the shore direction-finding station. Mean systematic errors up to ten degrees were observed, and Duckert satisfies himself that their relative magnitude from time to time and from station to station can be ascribed solely to the aerological situation in each case. In particular he discriminates between cases in which the reciprocal bearings have opposite and approximately equal errors, due to a discontinuity between stations, and cases in which one station shows much larger errors than the other because of local meteorological effects

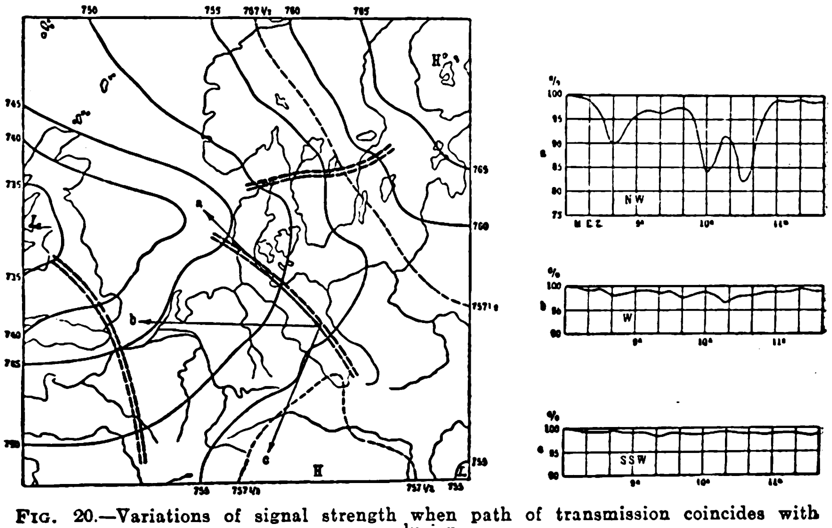


FIG. 20.—Variations of signal strength when path of transmission coincides with occlusion.
25th February, 1925.

at the receiver. While Duckert refers these effects to processes in the lowest layers of the atmosphere, and thus to purely lateral deviation of the received direct ray, it is well to remember that the normal direction-finder is not a suitable instrument for conclusive determination of lateral deviations, and it would appear most desirable that observations of this character should be repeated with the much more satisfactory azimuth-finder which can be produced by the use of an Adcock type of antenna system in the cathode-ray direction-finder. Such an instrument, which is instantaneous and direct reading, could, by very simple special adjustments, be given a very high discriminating power in the study of small errors of bearing.

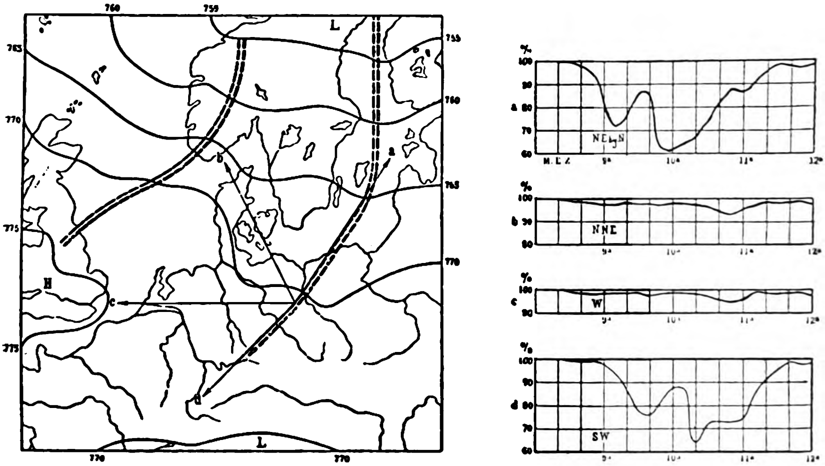


FIG. 21.—Curves of Relative Signal Strength against time, along various paths, showing diminution of signal strength along axis of occlusion.

19th March, 1925.

THE EFFECT OF WIRELESS ON WEATHER.

The most significant reference under this head dates from the year 1752, and it is of such importance that I quote here a complete chapter, in translation from the original Danish of Niels Horrebow.

"The Natural History of Iceland—interspersed with an account of the island by Mr. Huderson—to which is added a meteorological table," translated from the Danish, London 1758, has an immortally brief chapter LXXII, "Concerning Snakes":—"There are no snakes to be met with throughout the whole island." I may, then, pass to the next section of my talk!

But, on second thoughts, since snakes have on occasion been seen where no snakes are, a glance at the quantitative side of this question may be justified. There have been not infrequent suggestions that since broadcast radiotelephony became general the weather has deteriorated, rainfall has increased. Pathetic appeals have been made that the British Broadcasting Corporation should take a holiday to enable the poor farmers to get in their crops. Now it is known to arithmetically-inclined meteorologists that the production of an inch of rain represents an expenditure of thermal energy at the rate of 8,000 horse-power per square mile, applied to evaporation, so that the annual rainfall of the English countryside is the product of an expenditure of energy at a rate averaging a third of a million horse-power per square mile, night and day throughout the year. Despite the overcrowded state of the ether, which is causing sleepless nights to the broadcasting authorities and administrations of the world, the total rate of emission of energy from the broadcasting aerials of Great Britain is 55 horse-power, of Europe not over 400 horse-power, and that for a relatively small fraction of the twenty-four hours, and over an area exceeding three and a half million square miles, so that the mean rate of emission of energy during working hours is certainly under 1/2000 horse-power per square mile for British and 1/10,000 horse-power per square mile for Europe. Now it must be remembered that all the fresh water in the world has to be brought to site by processes essentially involving evaporation. Thus any mechanism which increases the total rainfall of the world must control energies of the order of magnitude which I have mentioned. But even if the mechanism merely effects the geographical redistribution of the normal quantity, any effect due to broadcasting must be a sort of trigger or catalytic effect of a singularly sensitive type in which the controlling element is in the sub-homeopathic proportion of one in a thousand million.

It is incredible that such effects should have escaped detection in the laboratory. We should be unable to see our wavemeter dials through the fog produced by switching on the oscillator! So I plead, in the ingenuous fashion familiar to students of libel suits, that the allegations are untrue, and that alternatively, if they are true, they should lie against the commercial wireless telegraphy stations, one of which alone, at Rugby, dissipates energy at nearly ten times the rate reached by the united broadcasting stations of Great Britain and Northern Ireland. Yet raincoats are not *de rigueur* at Rugby!

If I may be allowed to divulge the hitherto unsuspected fact that I am a Scotsman, by talking in the familiar units of my race, artificial rain for your tennis court would, if purchased at a favourable rate in the form of electrical energy, be worth £800 a year, while you pay only one eighth of a penny a year for your share of the radiated power of the British Broadcasting Corporation. I am indebted to Captain Eckersley for the information that he spends only ⅛d. per year on transmitter power from London for each London licence holder, the corresponding figure for the whole of the stations of the British Broadcasting Corporation being ¾d.

Incidentally I may revert for a moment to the third of a million horse-power required to provide our square mile of rainfall, in order to bring it into some sort of comprehensibility. One of the greatest achievements of British engineering is the great super-power station at Barking, the largest electricity generating station in the British Isles, burning a thousand tons of coal a day, having the only meters I have ever seen graduated in megawatts, and looking, as you may see, a most impressive monument of engineering enterprise. It is, then, a salutary comment on the limitations of human powers that this gigantic plant, applying itself night and day all the year round to the business of rainmaking by evaporation, could just keep a square mile around itself sup[illegible] with its normal allowance of rain. If, contrary to the gen[illegible] tendency which I have mentioned, one is unduly pessimistic about the powers of mankind, it is perhaps a little cheering to feel that, although rainmaking on the practical scale is beyond us, it isn't very, very far beyond us, but only as far beyond us as one Barking per square mile!

Wireless and Weather Warnings: Part II.

The first section under this title dealt with the *fait accompli,* the utilisation of artificially generated electromagnetic waves for the transport of artificially coded (I use the word "coded" in its widest significance) intelligence. This utilisation will, of course, be extended as the art of radio communication develops. We have to-night seen one of the most recent practical steps, and I have no doubt that ere long the airship navigator will have his synoptic charts still better suited for the quick interpretation that is essential to him, by wireless transmission in several colours. This is no fantasy, but I will not go so far as to say that a television transmission showing the central forecaster's views of the "probable motion of air masses for the next six hours" is an early requirement of the air navigator.

This section, however, is concerned with the possible utilisation, in the service of forecasting, of the weather of wireless. It contemplates the addition, to the existing machinery of synoptic observation, of a group of observations on naturally occurring phenomena in radio wave propagation, to be utilised as signals of frontal activity and meteorological disturbance. These observations would be supplements, on a comparable footing, to the present day observations of pressure, temperature, humidity and air velocity.

The first application of this kind to present itself is thunderstorm detection and location. It is a quarter of a century since Popoff installed the first radiotelegraphic thunderstorm detector; it is eighteen years since Erskine-Murray proposed direction-finding on thunderstorms; and it is nearly fourteen years since Cave and Whiddington made promising experiments on the location of thunderstorms by direction-finding. These years have not been fourteen years in the wilderness, rather have they been years of apprenticeship in the tool room, where strange new tools are being fashioned for the meteorologist. If we as radiophysicists have told him that he can no more fix the positions of thunderstorms by listening to atmospherics in a hand-rotated frame than he can solve a problem of ten variables with two equations, we have built him the new tool that separates some of the variables, and have shown, in our test-room which is of the size of a continent, that it does some of the things he wants it to do, though it may err by excess of zeal in doing rather more than he asked of it! But in all seriousness we ask for his close collaboration in determining the extent to which, together, we can interpret the messages it receives. Together we must determine whether its usefulness in his daily work can be increased by diminishing its sounding range, and whether such diminution of range can be effected by working on wave-lengths which, although disturbed by signals, may give higher attenuation of the atmospherics from distant sources and give greater prominence to sources at moderate distances. We ask him to consider with us how far he can use its great sounding range to economise by opening the mesh of the network of stations needed to give aerological data for long air routes.

We have built him another tool, which, if Herath and Bureau are right, may supplement—Bureau would almost say supplant—the barograph as an indicator of the passage of fronts over his observing stations. If indeed any large proportion of atmospherics originating at surfaces of discontinuity are of appreciable intensity at small distances only from their source, then a simplified form of the integrating recorders of atmospheric intensities will show the passage of a front.

Again, if Herath and Duckert are right, he and we may build in our workshops yet another telescope through which to watch the progress of these surfaces of discontinuity which are so clearly visible in the text books and so difficult for the unskilled to see on the synoptic chart. If we can reverse the Lindenberg process, and infer from intensity or directional measurements on the direct ray the nature of the intervening fronts, we can add another clue to the meteorological chart.

And finally we offer him at a venture an untried weapon. We ask him to take the samples of ionisation densities brought down by our electromagnetic wave gun and to tell us how the phenomena in the troposphere are related to the electrical state of the ionosphere.

Thanks are due to the Director of the Meteorological Office, the Director of Airship Development, and the Head of the Signals Branch of the Air Ministry for facilities for the transmission of synoptic data from Cardington; to Messrs. L. McMichael Ltd. for the reception arrangements, to Messrs. Wireless Pictures (1928) Ltd. for the picture transmission and recording by the Fultograph process, to Messrs. Carl Zeiss (London) Ltd. for the projection arrangements using the Zeiss Epidiascope, to the Department of Scientific and Industrial Research for permission to demonstrate the Cathode-Ray Direction-Finder, and to the staff of the Radio Research Station for the demonstration. I am particularly indebted to Mr. M. A. Giblett, Superintendent of the Airship Meteorology Division of the Meteorological Office, for much help and advice.

Visit of the Society to Rothamsted

Fellows of the Society and their friends, to the number of over 50, spent an enjoyable and instructive afternoon at the Rothamsted Experimental Station, Harpenden, Herts, on Wednesday, 12th June, 1929, by kind invitation of Sir John Russell, F.R.S., Director of the Station.

* * * * * *

The work at Rothamsted broadly consists of research into all branches of agricultural science.

The founder of the station was Sir John Lawes, a wealthy landowner, who laid out the experimental fields in 1843. He secured the services of a young chemist, afterwards Sir Henry Gilbert, to take charge of the scientific side of the work. Lawes and Gilbert carried out numerous classical researches, including a long and valuable research into plant nutrition and plant fertilisers, which led to one of the greatest agricultural advances of the nineteenth century. Before his death Sir John Lawes took steps to provide funds for the continuation of the work, but in recent years much additional development has been rendered possible by yearly grants from the Ministry of Agriculture and Fisheries. Considerable additions to the laboratories and to the area of the farm have been made, and in 1926 the Experimental Station at Woburn was taken over. The area of the fields at Rothamsted is about 280 acres, and of these the experimental fields, laid down by Lawes and maintained substantially unchanged ever since, account for 50 acres.

It is obvious that the weather, which exercises such a profound influence on agricultural operations and on crop growth, must enter into the research programme at Rothamsted, and from the beginning a meteorological station formed part of the regular equipment. Latterly this work has been developed in conformity with the requirements of the agricultural-meteorological scheme of the Ministry of Agriculture and Fisheries, which is under the control of a Committee of which Sir Napier Shaw is chairman, and at the present time the statisticians at Rothamsted are preparing to examine the detailed results of observations of crop yields in relation to the concomitant observations of the weather. These data have been collected during the last few years at Rothamsted and at more than 20 other stations situated at agricultural colleges and research institutions in various parts of England, Wales and Scotland.

* * * * * *

The party met at Rothamsted at 2.30 p.m., and, after being divided into groups of about 15 members each, was conducted round the various departments of the laboratories by members of the staff who had been specially deputed to act as guides. The work which is being carried out in each department was clearly explained, and the party was afterwards invited to tea with Sir John Russell and the senior members of the staff in the hall of "The Red Gables," a charming old-world house situated close to the laboratories, which has recently been taken over by the station as an office block and general meeting room for scientific discussions of the members of the staff. After tea, Sir Richard Gregory, President of the Society, in an appropriate speech, thanked Sir John Russell and his staff for their kindness in devoting their afternoon to the exposition of the work being carried out at Rothamsted, and for their hospitality, and mentioned that the work at Rothamsted was famous throughout the world of agricultural science, and found applications in every part of the globe. After tea a visit was paid to the first-order meteorological station, where, in addition to the usual work of a meteorological observatory, there is a very complete installation of recording soil thermometers. The percolation gauges and the large rain-gauge, each with collecting area of one thousandth of an acre, were also examined with interest.

R. C.

DISCUSSION OF MEMOIRS

L. H. G. DINES, M.A., AN ANALYSIS OF THE CHANGES OF TEMPERATURE WITH HEIGHT IN THE STRATOSPHERE OVER THE BRITISH ISLES

[Vol. 2, No. 18. Published April 1928—Read April 17, 1929.]

SUMMARY.

The Dines meteorograph, when employed with balloons giving a rising velocity of about 200-250 metres per minute, is not sufficiently well ventilated to yield accurate readings of the temperature of the air in the upper part of the stratosphere during the hours of daylight. In such cases an average error of about +3°C. appears to exist in the ascending record at a height of (H_0+6) km. and increasing above. The corresponding error in the descent in this region is believed to be insignificant.

The average temperature distribution in the stratosphere over the British Isles consists of a pronounced inversion of 3°C. at the bottom, followed by a lapse of about 0.5°C. per km. from (H_c+3) km. upwards to at least (H_c+8). There is no significant connection between the magnitude of the inversion and either the lapse rate just below it, or the temperature in the troposphere in the layer 3½ to 7½ km.

Individual soundings into the stratosphere show considerable departures from the average distribution of temperature, but as the height above H_0 increases there is a definite tendency towards a lessening of the dependence of the temperature on T_0. At a height of (H_c+17) the variations in temperature may possibly be independent of T_c.

Such evidence as is available is against the existence of a diurnal variation of temperature in the stratosphere.

DISCUSSION.

Sir RICHARD GREGORY: We are all familiar with the curve showing the mean variation of temperature with height, and Mr. Dines's examination of variations from the mean curve, with a view to determining their types and the causes which produce them, is of real scientific interest. It is by the study of such differences that new principles are discovered; and we welcome, therefore, this evidence of departures from mean temperature variations and the attempt to account for them. I invite comments upon the paper from Fellows who have given attention to upper-air research.

Sir G. T. WALKER suggested the possibility that the mean curve obtained was dependent on the criteria used for fixing the lower limit of the stratosphere. He had seen cases in which criteria widely adopted led to estimates which were in some cases very doubtful, and it seemed that care had to be taken in deciding how far the results obtained were independent of the criteria adopted. He thought that the indications that conditions above a "high" and a "low" were identical at about 25 km., like the relationships of temperature and stratospheric height with pressure, were naturally explained in terms of Exner's currents of equatorial and polar air; for these would probably not extend to a height greater than 25 km.

Mr. Dines, in reply, said Sir Gilbert Walker asked how the height of the base of the stratosphere was determined. The criteria adopted were those of Gold, and are to be found in *Meteorological Office Geophysical Memoirs,* No. 13, p. 59. In practice he had not found any great difficulty in interpreting the rules, and it did not seem likely that the conclusions reached had been seriously affected by such uncertainty as does occasionally exist.

In reply to Dr. Whipple, who referred to the method of classification of the data adopted, and pointed out that it was the same as had been used some time previously by Dr. G. M. B. Dobson in dealing with wind direction and velocity in the stratosphere, Mr. Dines said that Dr. Dobson's paper had suggested to him the idea of using the base of the stratosphere as the datum in the present case, and he took this opportunity of acknowledging his indebtedness to Dr. Dobson for the idea.

The late W. H. DINES, F.R.S., and L. H. G. DINES, M.A., MONTHLY MEAN VALUES OF RADIATION FROM VARIOUS PARTS OF THE SKY AT BENSON, OXFORDSHIRE

[Vol. 2, No. 11. Published November 1927—Read April 17, 1929.]

Summary.

The paper consists chiefly of four tables of monthly mean values of radiation from the sky observed at Benson, Oxfordshire, during the five years 1922-1926. The radiation is dealt with under two heads (1) Luminous rays, (2) Dark heat rays of wave length exceeding about 2μ. Each is measured under conditions of (1) Clear skies, (2) Completely overcast skies. The conditions under which the observations were made are stated and a few of the more salient features of the tables are briefly discussed.

Discussion.

Sir Richard Gregory: The instrument used for the observations discussed by Mr. Dines is of that simple and effective character which is associated with every instrument devised by his esteemed father. To me the point of particular interest mentioned is the increase of long-wave radiation from the grass field in comparison with that from the six zones of higher altitude. Even the short-wave radiation from the ground is greater than that from five of the six zones. This result might possibly have been anticipated for the long waves but not for the short. Mr. Dines's paper supplements to some extent the observations of radiation from the night sky made by Lord Rayleigh and continued at the Canberra Observatory by Dr. Duffield, who has recently published a memoir on the subject. Dr. Whipple has given much attention to radiation studies, and perhaps he will favour us with some remarks upon Mr. Dines's paper.

Dr. F. J. W. Whipple said that the Benson radiometer was a fine example of Mr. W. H. Dines's skill in designing instruments, and the *Memoir* in which the observations had been summarised was a notable addition to the literature on radiation. The observations had already proved a valuable check on theoretical discussions of atmospheric radiation and absorption. The series of observations would not lapse, as the apparatus had been set up at Kew Observatory and was already in operation there.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

March 20, 1929

At the *Ordinary Meeting* the following were balloted for and elected Fellows of the Society:—

Ronald Desmond Forsyth, c/o P. & O. Steam Navigation Co., 122 Leadenhall Street, E.C.1;

Pursholtam Muzhji Kabali, Alice Building, Hornby Road, Fort, Bombay;

Cyril Eyton Kay, Flying Officer, R.A.F., New Zealand House, Strand, W.C.2; and

Nevin Russell McCurdy, B.Sc., Royal Alfred Observatory, Mauritius.

April 17, 1929

At the *Ordinary Meeting* the following candidate was balloted for and elected a Fellow of the Society:—

Captain Otto Fulton, Dorland House, Regents Street, W.1.

Dr. J. Glasspoole gave an informal talk on the drought of March and dry weather from the beginning of the year (see p. 312).

CORRESPONDENCE AND NOTES.

Appointment

Dr. Lewis F. Richardson, F.R.S., who is in charge of the Physics Department, Westminster Training College, has been appointed Principal of Paisley Technical College.—*Nature*, June 22, 1929.

Fogs during Winter with unsaturated Air at various Town, Rural and Seaside Stations in the British Isles

It has been known for a long time that fogs may occur in large towns with relative humidities well below 100 per cent. owing to the part played by smoke; and recently Sir Napier Shaw has suggested,[1] following work by J. S. Owens, that fogs with unsaturated air may also occur on coasts, ascribing the cause in this case to the fact that particles of salt collected near the sea may be so hygroscopic as to become liquid drops in an atmosphere with a relative humidity so low as 75 per cent. and thus may " form the basis of fogs of considerable density in circumstances which are not otherwise suggestive of fog."

The present note is an attempt to display the frequency with which fogs have occurred in winter with relative humidities of less than 100 per cent. at various stations in the British Isles, town sites, seaside sites and rural sites all being considered. One result of the survey has been to show that even in rural sites, where smoke aggregations are most unlikely and which are at some distance from the sea, there are still occurrences of fog with air that is not even approximately saturated.

The results obtained in the survey are set out in the accompanying table. All the data used were obtained from the *Daily Weather Reports* issued by the Meteorological Office, London. " Winter " is defined as the months October to March (both inclusive), and a fog as a visibility of less than 1,100 yards. For the stations marked " A " in the table the period brought under review stretched from October 1st, 1923, to

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[1] Sir Napier Shaw. " Manual of Meteorology." Volume II., p. 43.

March 31st, 1927, and the hours of observation employed were 7h., 13h., and 18h. G.M.T., while for stations marked "B" the period was October 1st, 1922, to March 31st, 1927, and the hours of observation 1h., 7h., 13h., and 18h. G.M.T. For the one station marked "C" the period was March 1st, 1924, to March 31st, 1927, and the hours 7h., 13h., and 18h. G.M.T. In every case it needs to be remembered that only the "winter" months, October to March (both inclusive), were used, and it also needs to be noted that in the construction of the table the first of the three columns of relative humidity contains all readings below 95 per cent., and the second all readings below 90 per cent. The relative humidities were in every case measured by the use of wet and dry bulb thermometers, and the visibility observations at the sea stations are those taken looking landwards.

Stations.	Observations (see text).	No. of cases of fog.	Number of such cases when relative humidity was less than—		
			95 %.	90 %.	80 %.
Town Sites—					
Kew	A	210	90	43	11
Birmingham	A	220	126	67	14
Seaside Sites—					
Wick	A	3	0	0	0
Aberdeen	A	20	6	4	0
Spurn Head	A	110	27	1	0
Gorleston	B	138	29	9	0
Felixstowe	C	86	6	1	0
Shoeburyness	A	133	58	35	4
Scilly	A	51	0	0	0
Pembroke	A	59	6	2	1
Holyhead	A	11	0	0	0
Blacksod Point	A	12	4	1	0
Rural Sites—					
Cranwell	B	279	14	6	2
Ross-on-Wye	A	121	22	8	1

Considering the results shown by the table, the large numbers of fogs at the two city stations with air that is not saturated, or even approximately saturated, are very significant with regard to the rôle of smoke in large industrial areas; while the numbers of fogs at certain of the seaside sites with unsaturated air suggest that Sir Napier Shaw's "salt fogs" are far from infrequent visitations. In this latter connection, however, the entire absence of any fogs at Scilly with air that is more or less unsaturated is noteworthy, for it would have been expected that salt would have played some part, at least, there. The figures for Shoeburyness also stand out as worthy of consideration. Yet again, the occurrence of fogs in unsaturated air at the two rural sites suggests that other nuclei than salt may be sufficiently hygroscopic to form the basis of fogs.

My best thanks are due to Mr. E. J. Barker, of the Meteorological Office, for unstinted and valuable aid in the somewhat heavy task of extracting the data upon which this note is based.

William H. Pick.

6th May, 1929.

Note on the Frequency of Occurrence of Sequences in a Series of Events of Two Types.

It is sometimes important to know whether a sequence of similar meteorological events has a real significance or is due to mere chance. For example, if one divided days into two categories—" dry " (D) and " wet " (W) and wrote down the letters for days in order one would get sometimes a sequence of D's, sometimes a sequence of W's, and sometimes an isolated D or W; or if one divided weather types of each week broadly into anticyclonic (A) and cyclonic (C) one would find sequences of A's, of C's, and alternations of A's and C's. To determine the significance of the sequences it is necessary to know what distribution one would get if pure chance determined it. The following note is intended to indicate in a simple way how the chance distribution may be found when the two categories occur on the whole with equal frequency.

Suppose we have two letters P and Q and that on any occasion when we select a letter we are just as likely to draw a P as a Q. Let us draw two letters. We shall get one of the following 4 sets :—

PP
PQ
QP
QQ

and we are just as likely to get one set as another. In the 4 sets there are 2 sequences and 4 isolated P's and Q's. Now take three letters. We shall get one of 8 sets :—

PPP QQQ
PQP QPQ
PPQ QQP
PQQ QPP

In these are :—

2 sequences of 3
4 sequences of 2
10 isolated P's and Q's.

Now take 4 letters. We shall get one of 16 sets. 8 of these are :—

PPPP PQPP
PPPQ PQQP
PPQP PQPQ
PPQQ PQQQ

and there are 8 others in which the first letter is Q instead of P. In these there are :—

2 sequences of 4
4 sequences of 3
10 sequences of 2
24 isolated P's and Q's.

We can now see an indication of rule. First, the total number of sets are 4, 8, 16, *i.e.*, 2^2 for 2 letters, 2^3 for 3 letters, 2^4 for 4 letters.

The number of sequences of all letters alike is always 2.

The number of sequences of all letters but one alike is always 4.

The number of sequences of all letters but two alike is 10.

We may now generalize. Suppose we take m letters :—

The total number of possible sets is 2^m.

Thus the total number of letters in all the sets is $m \times 2^m$.

This total number must be equal to the number of sequences of m, $m-1$, $m-2$, etc. letters, multiplied by m, $m-1$, $m-2$, etc., and added together, *i.e.*,

$$m \times 2^m = 2 \times m + 4(m-1) + 10(m-2) + \ldots + x_{m-1} \times 2 + x_m \times 1.$$

where x_{m-1} and x_m are the $(m-1)$th and mth terms in the series 2, 4, 10, 24, . .

Similarly

$$(m-1)\,2^{m-1} = 2(m-1) + 4(m-2) + 10(m-3) + \ldots + x_{m-1} \times 1.$$

Subtracting we get

$$m(2^m - 2^{m-1}) + 2^{m-1} = 2 + 4 + 10 + \ldots + x_{m-1} + x_m.$$

Similarly

$$(m-1)(2^{m-1} - 2^{m-2}) + 2^{m-2} = 2 + 4 + \ldots + x_{m-1}.$$

Subtracting again we find (noting that $2^m - 2^{m-1} = 2^{m-1}$)

$$x_m = 2^{m-2}(m+2).$$

If m is very large, the number of isolated letters which are to be expected in any random choice of m P's and Q's is

$$\frac{2^{m-2}(m+2)}{2^m}$$

i.e., the number in all the possible sets divided by the number of sets. This is

$$\frac{m+2}{4}$$

The number of sequences of 2 will similarly be

$$\frac{2^{m-3}(m+1)}{2^m} = \frac{m+1}{8}$$

i.e., about half the number of isolated letters.

The number of sequences of 3 will be $\frac{m}{16}$

4 ,, ,, $\frac{m-1}{32}$

and so on.

We see from this that about half of the letters in a long set occur as isolated letters or in sequence of 2, while the higher sequences take the other half of the letters.

If we take as an example the 365 days of an individual year, then if pure chance governed the question of dry or wet days we should get about 92 isolated dry or wet days, 46 sequences of 2 dry days or 2 wet days, 23 sequences of 3 dry days or 3 wet days, 11 sequences of 4 dry days or 4 wet days, 5 sequences of 5 dry days or 5 wet days, and about 2 wet or dry weeks.

Mr. Newnham in 1916 (*Q.J.R. Meteor. Soc.*, **42**, 1916, p. 154) published a table showing the frequency of isolated rain days and fine days and of sequences of 2, 3, 4, etc. rain days and fine days in a period of 10 years at Kew, where on the average there are about as many rain days as fine days. The following table compiled from Mr. Newnham's values shows the comparison between actual and chance in this matter.

Number of days in sequence	Actual number of occurrences	"Chance" number
1	631	914
2	285	457
3	187	228
4	90	114
5	61	57
6	43	28
7	22	14
8	22	7
9	10	3
10	9	2

It is fairly clear that the higher sequences are not pure chance—and there is, therefore, some possibility of predicting them.

Another example is furnished by a recent investigation of Dr. Brooks and Miss Quennell into weather types and sub-types. They took 10 years, and gave to the pressure distribution of each of the 3 ten-day periods of a month a class I or II and sub-classes A, B, etc. There were 360 periods in all, and the following small table shows the number of actual sequences of I or II and the number which would have been expected if pure chance had determined the distribution :—

Periods in sequence	Actual number of occurrences	"Chance" number
1	69	90
2	47	45
3	19	22
4	11	11
5	10	5
6	1	2
7	2	1
8	2	—
9	1	—

I was led to write this note because when I first saw the sequences of 5, etc., in Dr. Brooks' and Miss Quennell's table I thought they indicated a real persistence; and I was surprised when I came to look into the question to find how great was the number of sequences one would expect if the occurrences were pure chance.

E. GOLD.

20th June, 1929.

Diurnal Variation of Pressure and Temperature at Cahirciveen (Valencia), 1871-1926.

The accompanying table gives the values of the constants in the harmonic series expressing the diurnal variation of pressure and temperature at Cahirciveen. It is similar to the table for Aberdeen published in the *Q.J.R.Meteor. Soc.,* 55, p. 198; is for the same period of years, and is derived from the same sources. The geographical co-ordinates involved are:—Latitude 51°56′N; longitude 10°15′W; height of barometer cistern above mean sea level 13.7 metres; thermometer 1.2 metres above ground level.

DIURNAL VARIATION OF PRESSURE AND TEMPERATURE AT CAHIRCIVEEN (VALENCIA), 1871–1926.

Constants in the Harmonic Series $c_0+\sum c_n \sin(15nt+a_n)$.

Month.	Pressure.									Temperature.								
	Mean.	Amplitudes.				Phase Angles (L.A.T.).				Mean.	Amplitudes.				Phase Angles (L.A.T.).			
	c_0	c_1	c_2	c_3	c_4	a_1	a_2	a_3	a_4	c_0	c_1	c_2	c_3	c_4	a_1	a_2	a_3	a_4
	mb.	mb.	mb.	mb.	mb.	°	°	°	°	a.	a.	a.	a.	a.	°	°	°	°
January	1012.162	.101	.317	.156	.069	164.6	157.5	257	218	280.26	0.48	0.26	0.11	0.02	238.6	53.7	227	48
February	1010.970	.124	.342	.115	.041	196.7	154.1	355	104	280.07	0.81	0.37	0.09	0.03	237.2	59.4	246	202
March	1011.486	.118	.357	.044	.038	159.1	154.4	269	58	280.31	1.34	0.42	0.04	0.08	236.6	64.3	334	224
April	1011.513	.101	.311	.035	.036	190.9	148.6	176	11	281.87	1.80	0.36	0.15	0.06	238.8	72.2	41	236
May	1013.579	.168	.273	.074	.017	179.3	145.3	163	343	284.28	2.08	0.19	0.24	0.04	240.8	96.7	55	305
June	1015.070	.196	.254	.079	.004	199.0	146.1	161	340	286.70	2.05	0.11	0.21	0.03	242.6	97.2	63	13
July	1014.099	.242	.248	.079	.013	184.4	145.3	165	16	287.95	1.86	0.15	0.20	0.01	244.0	78.0	63	344
August	1012.805	.252	.278	.054	.034	189.0	145.2	165	348	288.02	1.74	0.30	0.16	0.03	243.4	70.5	49	243
September	1014.063	.193	.344	.002	.044	201.9	150.1	46	1	286.60	1.55	0.45	0.06	0.09	240.0	67.5	212	228
October	1010.660	.202	.336	.071	.014	194.4	153.3	349	42	283.97	1.11	0.41	0.08	0.07	236.6	58.5	260	207
November	1011.127	.076	.343	.128	.034	180.7	154.5	355	153	281.54	0.72	0.35	0.12	0.01	236.0	55.5	242	102
December	1009.869	.130	.317	.158	.074	190.5	158.3	355	194	280.57	0.44	0.26	0.11	0.03	232.6	52.8	238	55
Year	1012.284	.155	.308	.030	.003	187.9	151.7	5	70	283.51	1.33	0.30	0.05	0.02	240.3	66.5	38	234

The following points are of some interest. The values of c_1 for pressure are higher in summer and lower in winter. The opposite was noted in the case of Aberdeen. It is hoped that this may be dealt with in a later note, but meanwhile it may be pointed out that Cahirciveen, on the record from 1881 to 1926, receives about 25 per cent. more sunshine than Aberdeen, whether in actual number of hours or in percentage of the possible maximum. The phase angles α_1 for pressure change less regularly throughout the year than at Aberdeen. The amplitude c_2 of the 12-hour pressure term exhibits the usual maxima about the time of equinox, and it is noteworthy that, as at Aberdeen, there is a corresponding change in value of the 12-hour term amplitude in the temperature series. Roughly speaking, for both stations a change of $\pm 0.1°$ in the 12-hour amplitude in temperature is accompanied by a change of $\pm .030$ mb. in the 12-hour amplitude in pressure. Phase angles α_2 for pressure show a yearly change which is very different at the two stations. Aberdeen has two maxima, in April and November, Cahirciveen a single maximum about midsummer. At Aberdeen it was noted that the amplitude of the 8-hour term in temperature tends to a minimum at the equinoxes as does the corresponding term in pressure. This is also the case at Cahirciveen.

A. CRICHTON MITCHELL.

Hurricane near the Fiji Islands

Captain Twentyman, of Suva, Fiji, has forwarded an account by M. L. Singleton, Master of the A.K. *Endeavour,* of a hurricane whose centre passed over the *Endeavour* on her way from Rotumah to Suva last February.

The *Endeavour* left Rotumah, about 300 miles north of the Fiji Islands, on Saturday evening, February 16, in a moderate Northerly breeze and a considerable north-west swell. During Sunday the barometer fell slowly and the breeze freshened from N by E. On Monday the sea was rough, the wind was variable from N by W to NNE and there were occasional squalls of heavy rain; the barometer fell steadily from 29.60 in.[1] to 29.56 in., and by the evening the wind had reached gale force. At 1 a.m. on Tuesday morning (February 19) a huge sea struck the *Endeavour,* smashing the door of the engine room and flooding the engine; after about an hour the engine stopped, and the crew had no option but to heave to. At 2 a.m. the barometer had fallen to 29.52 in., the wind was "at heavy gale force," and there was a "heavy confused sea . . . running two ways, sometimes from right abeam and sometimes from right aft." The barometer fell very rapidly during Tuesday to a minimum of 28.74 in. at 5 p.m., when the wind and sea suddenly subsided to a dead calm. "There was a weird colouring of a dull red on the clouds to the *eastward,* and underneath the red were shades of green and yellow that I can only describe as sickening. I gave orders to secure everything as quickly as possible, but before we had half finished doing so, at 5.40 p.m., a breeze sprang up from the SW., rapidly increasing until at 6 p.m. it was terrific, with increase during squalls, which at first came with scarcely an interval between them. I experienced considerable difficulty in breathing. The wind lifted continuous spray over the ship, which struck my face, arms and legs with a force that I can only describe as if a person of average strength was pelting me with handfuls of small pebbles. Seas were breaking over the bulwarks continually. Suddenly the lifeboat was lifted in the air from the starboard side of the deck and dashed overboard. I cannot swear to it, but as I saw no sea break over at the time I concluded it was the wind that lifted it. The bowsprit which I had noticed jerking violently snapped off close to the heel, and the forestay snapped. At 8.20 p.m. the wind and sea dropped, and at 9 p.m. it was practically calm with a big heavy swell.

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[1] The ship's barometer, when compared with the barometer in the Meteorological Office at Suva, was found to be reading 0.18in. too high.

I wish to state that I was particularly taking notice of the sea, and there was absolutely no pyramidal sea as described in the old "Law of Storms" of our day. The wind and sea ceased at 5 p.m. and immediately went to calm; at 5.40 p.m. it resumed from a gentle breeze to redouble gale and the sea accommodated itself to the new direction of the wind. At 8.20 p.m. the barometer rose to 28.80 in. and continued rising slowly.

On Wednesday, February 20 I got observations in beautiful clear weather, making my noon position: lat. 20°20'S. and long. 177°14½'E. At 2.7 p.m., having cleared the water from the engine room, we resumed our passage to Suva, arriving at 6.30 p.m."

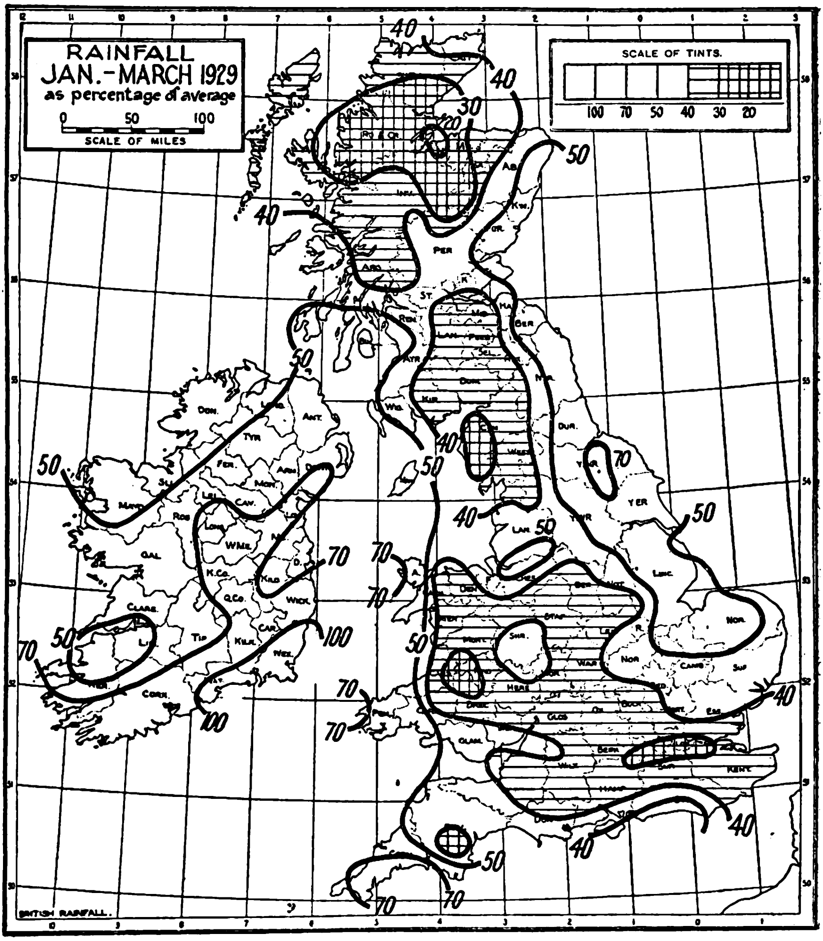
The latitude of Suva is 18°8'S. The *Endeavour* appears to have been driven south of her course. The hurricane was probably travelling in a south-easterly direction.

The Dry Period of January to March, 1929

Some details of the rainfall of the dry period of January to March, 1929, were given by Dr. J. Glasspoole during the informal five minutes' talk at the meeting on April 17th.

During these months there were three main types of pressure distribution. During most of *January*, pressure was much higher than usual over the north of Scotland, and Northerly and Easterly winds occurred with considerable frequency. January was particularly dry in the north of Scotland, but more rain than usual fell along the east coast of Great Britain. During *February* the trend of the isobars was from south to north, and while the weather was intensely cold in Great Britain, the south of Ireland, with SW. winds, was slightly warmer than usual. In February, while most of Great Britain received less than half the average rainfall, in the south of Ireland there was twice the average. The weather of *March* was dominated by high pressure systems centred over the British Isles, sunny weather prevailed with large diurnal range of temperature and the drought was intensified. Over the country as a whole March, 1929, was the driest March since before 1870, and ranks with February, 1891, and June, 1925, as the driest months on record. There was no rain at all at a few stations near London, and only about one tenth of an inch over about half of England and Wales, including central and south-eastern districts.

Over the British Isles as a whole the rainfall of January to March, 1929, was half the usual amount, and less than that of any similar period in the last 60 years, the next driest being that of 1891, with 60 per cent. of the average. In the diagram the rainfall is shown as a percentage of the average for that period, the areas where the drought was most intense being shaded. There was more rain than usual in the south of Ireland, as a result mainly of the SW. winds in that area in February. The falls of relatively large percentage along the east coast of Great Britain, associated with the E. winds of January, are also well marked. The drought was both widespread and intense in Scotland, where all three months were unusually dry. At Ardross Castle, near Alness, the period included both the driest January and the driest March of the last 60 years, and there the total rainfall was less than that of any other three consecutive months.


RAINFALL
JAN.-MARCH 1929
as percentage of average
0 50 100
SCALE OF MILES
SCALE OF TINTS.
100 70 50 40 30 20
40
30
20
50
70
100
BRITISH RAINFALL.

There were four areas with less than one third of the average—a narrow strip across the Thames Valley from Gloucester to Margate, Central Wales, the English Lake District, and much of the northern half of Scotland. The total for January to March at Gloucester was only 1.27in., and at Shoeburyness only 1.18in. There was less than 2in. for these three months in the Midlands, near Oxford, London, and the Thames Estuary, and in the neighbourhood of the Moray Firth. The conditions do not seem to have been quite as severe (up to the end of March) as during the famous spring drought of 1893, when in the south-east of England there was no rain for a period of 50 days and only about 1.1in. in 110 days or 3½ months. One of the main features of the weather of January to March, 1929, was the marked weakening of the SW. winds and consequent deficiency of rainfall in the mountainous areas. Parts of the English Lake District and the Western Highlands of Scotland received 10in. or 25in. less than usual during this period.

Snow Temperatures in Switzerland.

We have received from Mr. J. E. Belasco an account of some interesting observations of temperature made by him during a visit to Wengen in Switzerland from January 6th to 27th, 1929, which illustrates in a striking manner the high protective value of a covering of snow. A level patch of snow about 2,000 square feet in area with a generally free exposure was selected as the site for the experiments. The thermometers used were lent by the Meteorological Office and were of the ordinary "grass minimum" type. One instrument, the "external thermometer," was supported on two forked twigs two inches above the level of the snow. Six inches from this a rectangular pit 18 inches wide and 36 inches long, was dug in the snow. At the commencement of the observations its depth was 12 inches, but this increased to about 26 inches by the time the record was discontinued in consequence of the accumulated snowfall. The principal falls of snow occurred on January 16th and 17th (4 inches) and again on from the 24th to 26th (10 inches). At the bottom of this pit and at right angles to the external thermometer, a horizontal tunnel about 4 inches in diameter and 16 inches in length was bored in the snow to take the second thermometer, subsequently referred to as the "internal thermometer." About one inch of snow separated the bottom of the pit from the underlying earth. The mouth of the tunnel was always kept closed by a piece of cardboard about one inch thick, which completely covered the entrance, and was only removed to admit of the entry or exit of the thermometer. The internal thermometer was placed flat on the

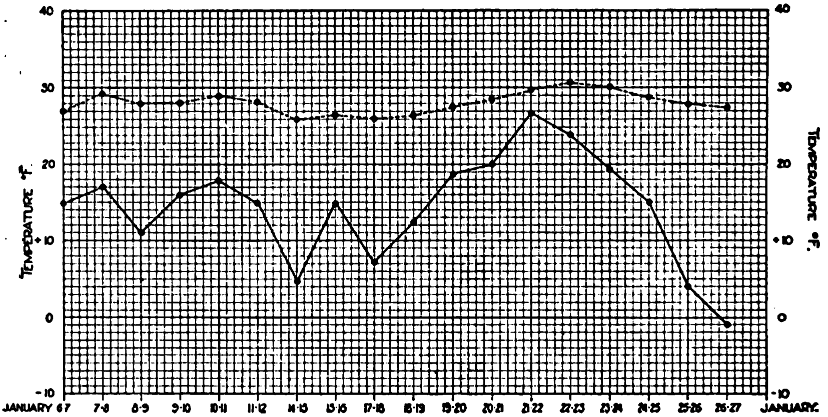


FIG. 1.—Minimum temperatures in °F., 2in. above the snow, and in a tunnel 12 to 26in. below the surface of the snow at Wengen.
Internal thermometer (in tunnel 12 to 26in. below surface of snow) - - - - - -
External thermometer (2in. above surface of snow) ————

snow, with its bulb farthest away from the mouth of the tunnel. Both thermometers were placed in position at about 1830 C.E.T. each evening, and the minimum temperatures were read the following morning. The results of the observations are shown on the accompanying diagram (Fig. 1). The general steadiness of the readings of the internal thermometer and their generally higher level as compared with the readings of the external instrument are very remarkable. The facts are also brought out by the following table of simultaneous readings, taken at the hour of morning observation, of the temperatures of the air at a level of about 5 feet observed with a whirling thermometer, of the temperatures just above the snow surface and of the temperature in the tunnel.

TABLE I.—COMPARISON OF TEMPERATURES IN THE FREE AIR, JUST ABOVE THE SNOW, AND IN THE SNOW.

Day. (Jan., 1929).	Hour. (C.E.T.).	Dry Bulb free air. 1	Temperature of air just above snow. 2	Temp. of air in tunnel in snow 12-26 inches below surface. 3	1–2.	Weather.	Remarks.
		°F.	°F.	°F.			
7	10.45	29.5	28.0	29.5	+1.5	o	Low cloud
8	10.20	23.0	17.5	29.8	5.5	bv	
9	10.00	21.4	12.0	28.2	9.4	bv	
10	10.30	24.5	19.3	28.5	5.2	b	
11	10.15	29.3	25.5	29.4	3.8	o	Low cloud
12	10.35	22.1	16.0	28.4	6.1	bv	
13	09.15	22.8	16.0	17.8*	6.8	b	*Bottom of pit
14	08.45	16.3	9.6	12.0*	6.7	b	,, ,,
15	09.20	11.0	7.0	26.2	4.0	c	High & med. cl.
16	09.20	19.5	17.5	27.2	2.0	oss	Low cloud
18	10.35	20.9	20.0	28.0	0.9	o	,, ,,
19	10.40	24.4	19.4	27.5	5.0	bv	
20	10.20	27.0	22.9	28.2	4.1	b	
21	10.20	29.2	23.2	29.0	6.0	c	High & med. cl.
22	09.45	34.2	31.8	30.2	2.4	os_0 s_0	Low cloud
23	10.20	30.4	25.7	30.8	4.7	b	
24	09.20	28.5	28.4	30.2	0.1	oss	Low cloud
25	09.30	16.8	15.9	29.2	0.9	omss	,, ,,
26	10.10	11.0	9.0	28.5	2.0	bcm$s_0 s_0$	Med. & low cloud
26	24.00	6.5	1.0	—	5.5	bm$s_0 s_0$	Haze
27	09.45	10.2	8.0	28.0	2.2	om.	Ci. haze

Mr. Belasco also draws attention to an interesting example of the check on radiation that a thin cloud layer may exert. At midnight on January 26th the air temperature was 6.5°F., while on the snow the reading was +1.0°F. To the casual observer the night was a clear one, with moon and stars visible, yet the minimum reading on the snow for the night was only −1.0°F. Except for a little cirrus and lenticular stratus which appeared from time to time passing over from north-east, the sky was clear from about 1800, but the whole of the basin surrounding Wengen was filled with a thin mist, so thin that the heavenly bodies and the outline of the more distant mountains could be seen. By the light of lamps, snow needles could be seen falling with moderate intensity with an occasional small snow flake. At 0100 a brilliant halo surrounded the moon, with a tinge of red inside the circle facing west, while there was a suspicion of a pale yellow-coloured corona touching the moon. These, however, quickly disappeared.

Empire Agricultural Meteorology

The following announcement of interest to meteorologists appeared in the *Journal of the Ministry of Agriculture* for April, 1929:—

"It has been decided to organise an Agricultural Meteorological Section of the Empire Meteorological Conference which is being held in this country under the auspices of the Air Ministry in August next. The organisation of this Agricultural Meteorological Section has been entrusted to the Agricultural Meteorological Committee, and the Secretary of that Committee, Mr. W. R. Black, M.B.E., B.Sc., has been appointed to act as Secretary of the Section at the Conference. Papers are being invited from workers in this country and overseas, and accounts of the organisation of agricultural meteorological work in this country, in the overseas Empire and in foreign countries, will be prepared. It is proposed that the question of co-operation in agricultural meteorological work in the Empire shall be further developed at the Imperial Agricultural Research Conference in 1932. The cost of organisation of the Agricultural Meteorological Section at the forthcoming Conference in August is being borne by the Empire Marketing Board."

A New Apparatus for producing Hydrogen

The *Oxhydrique Française* have constructed a portable apparatus which will produce hydrogen instantaneously and under compression, known as the H.I.C. hydrogen generator. The hydrogen is produced by the action of caustic soda on ferro-silicium. Instead of operating at atmospheric pressure, however, the reaction takes place in a closed vessel, the gas being automatically obtained under pressure and free from water vapour; thus apparatus for condensing this vapour (necessary with other methods) is not required. There are two models; the smaller one weighs 45 kilogrammes and can produce 500 litres (110 gallons) of hydrogen per charge, the larger one weighs 73 kilogrammes and produces 800 litres (176 gallons) per charge; in addition each model has a stand weighing 15 kilogrammes.

The apparatus is easily transported and it consumes only a small quantity of water; it should therefore be useful for pilot-balloon work in isolated regions.

Hand Anemometer for measuring Winds near the Surface

Dr. Oepik, of the Astronomical Observatory, Tartu, Estonia, has designed a small portable anemometer for the measurement of air currents near the surface. It consists of three wings or plates of thin sheet nickel, balanced on thin axes, by means of which the velocity, the direction and the inclination of the wind can be measured. The wing for measuring velocity, besides the counterpoise for balancing the weight, has one permanent and two detachable counterpoises, which measure velocities of 0.2 to 1.9, 0.9 to 7.7, and 2.7 to 24 metres per second respectively. It is claimed that the construction of the wings is delicate enough to give reliable observations of velocities as low as

0.3 metres per second, and is simple and firm enough for the instrument to be used by untrained observers without fear of injury.

In the measurement of variable winds such as occur near the surface the wing anemometer is less subject to error than the cup anemometer owing to the greater inertia of the latter instrument. The anemometer is held in the outstretched hand; four to eight readings should be taken of each wing to obtain a reliable value. The probable error of readings, deduced from sets of observations of the direction and inclination wings, gives a measure of the turbulence of the air near the ground.

The instrument is supplied in a box with instructions and tables for the reduction of readings for $15.

OBITUARY.

Lord Montagu of Beaulieu.

The death occurred on March 30, 1929, at a nursing home in London of Baron Montagu of Beaulieu, K.C.I.E., C.S.I., aged 62.

John Walter Edward Douglas-Scott-Montagu was the son of Lord Henry Scott-Montagu, official Verderer of the New Forest. He was educated at Eton and New College, Oxford. After leaving college he joined the L. & S.W. Railway, where he made himself a competent mechanic and locomotive driver. In 1892 he was elected Conservative member for the New Forest division of Hants, which he represented until he succeeded his father in 1905.

Lord Montagu had a great many activities, but he will be chiefly remembered as a pioneer of motoring and an authority on road transport. He was one of the first members of the Royal Automobile Club, and he took King Edward VII. for his first motor drive. In the early days of motoring he travelled about the country combating prejudices to, and explaining the advantages of the new method of locomotion; he also worked at the mechanical improvement of the car. He founded and edited for many years *Car Illustrated.* Going to India with his regiment at the outbreak of war, he was appointed Adviser on Mechanical Transport Services to the Government of India; his services in this capacity were recognised by the C.S.I. in 1916 and K.C.I.E. in 1919.

Lord Montagu also took an active interest in aviation, and he frequently addressed the House of Lords on subjects connected with air policy. In 1917 he lectured on aviation in the principal cities of Canada.

As Verderer of the New Forest Lord Montagu had an expert knowledge of the Forest and its fauna and flora.

He was elected a Fellow of this Society in 1907.

Joseph Hawksley.

We regret to announce the death on May 1, 1929, at Ryde, of Joseph Hawksley, aged 62. Mr. Hawksley was for 28 years Engineer and Manager of the Great Yarmouth Waterworks Company and the Lowestoft Water and Gas Company. Born at Norton Lees, near Sheffield, he began his professional career on the staff of the Waterworks Engineer of Sheffield. In 1895 he became Assistant Engineer to the

Portsmouth Waterworks Company, and from there he went in 1900 to Great Yarmouth. He retired in April, 1928, on account of ill-health. Mr. Hawksley was also for many years a member of the Executive Committee of the British Waterworks Association.

He was elected a Fellow of this Society in 1907.

Miss ISABELLA McNAB.

We regret to announce the death on December 24, 1928, of Miss Isabella McNab, of Blackruthven, Perth, and of Belgrave Crescent, Edinburgh.

Miss McNab was a life Fellow of the Scottish Meteorological Society and was elected in 1906.

Mr. M. A. ROBINSON, M.Inst.C.E.

The death occurred on February 16, 1929, of Matthew A. Robinson, M.Inst.C.E., M.R.I.A.I., City Surveyor and Engineer of Londonderry, at the age of 56. Matthew Robinson was one of the members of the large family of the late Rev. W. C. Robinson, Presbyterian Minister of Ballykelly. He served his apprenticeship in Belfast, where he gained a large experience; he was a member of a private firm in Londonderry before he became City Surveyor. During the twenty years of his office as Surveyor he was responsible for a great many improvements in the town. He was an exceptionally clever architect, a mechanical engineer both in theory and practice, and an authority on hydraulic engineering. But the biggest piece of work of his life, in fact, the greatest engineering undertaking ever embarked upon in Londonderry, was the scheme for bringing a supply of water from an untilled catchment area in the Banagher district of County Derry, and that was uncompleted at the time of his death. However, the care and thoroughness with which his plans were laid should enable his successors to carry out the scheme successfully.

Mr. Robinson was elected a Fellow of this Society in 1902. He always attended the meetings of the Society when they coincided with his visits to London.

REVIEWS.

The Life and Work of Sir Norman Lockyer. By T. MARY LOCKYER and WINIFRED L. LOCKYER. London (Macmillan & Co. Ltd.). 8vo. Pp. xii. and 474. 18s. net.

The record of a life so long, so strenuously active and so many-sided as that of the subject of this memoir inevitably presents difficulties to a biographer wishing to keep the memoir within the limits of a single volume; and in a foreword the authors acknowledge their indebtedness to Prof. H. Dingle, of the Royal College of Science, whose co-operation in the task of constructing an orderly biography from the large collection of documentary and other material was so extensive that he is credited with being "largely responsible for the composition of the chapters devoted to the general biography." This task has been admirably accomplished.

The reader is carried briskly on from stage to stage of the fascinating story of Lockyer's pioneer researches in spectroscopy and solar physics, capturing at times something of the excitement first experienced as telescope or laboratory revealed new facts and opened up new vistas in discovery.

One is impressed with Lockyer's extraordinary capacity for work as a young man. "The more one has to do, the more one does" was one of his *dicta*; and we read that in the eighteen-sixties his daily routine frequently included volunteer drill on Wimbledon Common and an hour's study at the British Museum *before* the commencement of his duties as a Government official in the War Office; while popular lecturing, heavy editorial work and laboratory research, added to arduous astronomical observing, filled the waking hours after the day's official labours were concluded.

When he was elected to Fellowship of the Royal Society, being already known to the whole scientific world for spectroscopic advances of highest importance, he was still at routine work in the War Office and not yet thirty-three years of age.

One is impressed also by the evidences of his sturdy independence of thought. Of his tenacious adherence to the bold hypotheses and acute speculations for which he was famous, then and later, probably the best example is the case of helium,—the unknown substance inferred by him in 1868 from a characteristic yellow line in the spectrum of solar prominences and appropriately named at that date, though not isolated in the laboratory and identified as an actual element till almost thirty years later. The "Story of Helium" is graphically told in Ch. XXIX. by a reprint from *Nature* of February, 1896.

Lockyer's varied interests brought him into contact with many of the leading men of Victorian times. He numbered among his friends such diverse personalities as Tennyson, Huxley, William Black and Holman Hunt.

One of the outstanding accomplishments of his career, the foundation and the editing for fifty years of *Nature,* receives perhaps less notice than it merits. The difficulties and anxieties of such a task must have occupied a considerable part of his attention.

The story of his gradual withdrawal from uncongenial duties at the War Office, *via* secretaryship of a Royal Commission on scientific instruction, to a post in the Science and Art department of the Board of Education makes interesting reading. His duties were at first "vague" but finally evolved into Directorship of the Observatory for the study of Solar Physics, which had been established at South Kensington under his guidance.

Lockyer took a special interest in meteorology, and it is recorded that when giving evidence before a Treasury Committee on the work of the Meteorological Office (1903) he claimed for their forecasts, as a matter of practical experience in the choice of stick or umbrella based upon them, eighty-five per cent. of successes.

An account is given of the time and labour devoted in his later years to the task of relating weather cycles—particularly tropical weather cycles—to the cycles of solar activity. This work, however, came to an abrupt end when in 1911 the Board of Education decided to transfer the Solar Physics Observatory from South Kensington to Cambridge. Lockyer's very natural disappointment at the decision, with its consequences to himself, are sympathetically recorded, and the biography draws to an end with an account of the steps he took to establish on his own responsibility the astrophysical observatory which it had been his aim to see established as a national institution.

The biography itself occupies twenty-six chapters. There follows a distinctly novel departure (made at the suggestion of Sir Richard Gregory) in the form of some 230 pages embodying a series of appreciative articles on Lockyer's pioneer work, written by present-day leaders in the same branches of research. These chapters have the character in some instances of miniature treatises, and constitute a very valuable addition to the biography.

The chapter by Prof. H. N. Russell, of Princeton University, U.S.A., is specially happy in its appreciations. As Prof. Russell observes: "(Lockyer's) ideas of stellar evolution, his 'dissociation hypothesis' and even the 'meteoric hypothesis' have in them the germ of the most modern theories in astrophysics." This characteristic is also referred to by Prof. Saha.

Quoting again from Prof. Russell: "His fame should grow as time passes. Not least among the pioneers of astrophysics in his observational contributions, in his insight into the true nature of its problems, he stands without a rival."

W. M. W.

Magnetic Disturbance and its relations to Aurora. By Charles Chree. *Australasian Antarctic Expedition,* 1911-1914. *Scientific Reports, Series* B, Vol. 2, Pt. 2. Sydney, 1929, pp. 193-331.

Auroræ and magnetic disturbance remain deeply mysterious phenomena, despite the years of study devoted to them by observers and theorists. Attempts to solve the problems which they present, by workers starting from different points of attack, have hitherto led only into tangled difficulties, and a meeting of the paths through the jungle is not yet in sight. Will some simple physical intuition suddenly lighten the dark places, or must we wait for a slow accretion and synthesis of knowledge as to solar and atmospheric and magnetic phenomena to displace ignorance only step by step? Such meditations are prompted by this posthumous work on the magnetic and auroral data of the Mawson Antarctic Expedition of 1911-1914. It is valuable and necessary to collect data of this kind, and there is need for much further observation of these phenomena both in the Antarctic and the Arctic; but it must be confessed that at present we do not know what to make of them. After nearly eighty pages of discussion, based on fifty-six tables of numerical data, no definite conclusions or leading features of the phenomena are described; regularities in the data are noted from time to time in the text, but only to be followed by qualifications, and a discussion of exceptions, which loom larger than the original rules. This painstaking and conscientious examination of Mawson's data is not easy reading, but it sets out, in order, some of the facts, won with great devotion and difficulty, which must be the touchstone by which to try proposed explanations of auroræ and magnetic storms. In a subject which has tempted many authors into ill-founded speculations, it is good to have the facts analysed by a mind as critical as that of Dr. Chree, which refused to overlook the complexities of nature.

S. Chapman.

The Electrical Conductivity of the Atmosphere and its Causes. By V. F. Hess. Translated from the German by L. W. Codd. London (Constable & Co.), 1928. 8vo. Pp. xviii. and 204. 12s.

That interest in atmospheric electricity is rapidly increasing is perhaps a legitimate deduction from the succession of books dealing with the subject which have appeared in recent years. In addition to articles in the German handbooks and to essays such as Kähler's "Elektrizität der Gewitter" (1924), we have had a second edition (1921) of the same author's small but excellent "Luftelektrizität." Then, on a larger scale, the French point of view has been represented by Chauveau's "Electricité Atmosphérique" in three volumes (1922-25) and by the treatise published under the editorship of Mathias (1924). Italian activity in the subject is represented by Prof. Carlo Negro's "Elettricità Atmosferica" (1926). Meanwhile, until this translation of Prof. Hess's "Die elektrische Leitfähigkeit der Atmosphäre" appeared early last year, no recent treatment was available for English readers except the necessarily very condensed article contributed by Prof. C. T. R. Wilson to the "Dictionary of Applied Physics," Vol. III (1923).

The books mentioned have shown wide variations of merit, but it cannot be doubted that none more worthy of translation than that of Prof. Hess could have been selected. The original German version was published in the middle of 1926. The growth of the subject has been so rapid that it has been found necessary, for the English edition, to rewrite and expand two important sections, those dealing with the "ultra-gamma" or penetrating radiations and with the electrical condition of the higher layers of the atmosphere. While both sections, at the present moment, stand in need of further additions, they are none the less of high value to the English reader. It is of special interest to have from Prof. Hess, who had such a large share in their discovery, a clear and, within the limits, fairly complete account of experimental work on the penetrating rays. The names of Gockel, Bergwitz, Kolhörster and Hess in connection with the original investigation of these rays, and of Hoffman in connection with later work, however familiar they may be to students of atmospheric electricity, are not so prominently before the minds of physicists in the English-speaking countries as those of Millikan and his collaborators. It is well that the balance should be redressed. But, as already indicated, it is inevitable that any such presentation as this should quickly find itself out-distanced by a rapidly growing subject.

By excluding the earth's field, its variations and maintenance and earth-air electrical interchanges, Hess has left himself free to give a very complete treatment of the remaining branches of atmospheric electricity in a comparatively short space. He deals with the ions in the atmosphere, their production, character, behaviour and final fate. This involves a critical account of the different methods of counting ions and measuring conductivity. As the major source of the production of ions, at least at low levels, the radio-activity of the soil and atmosphere is dealt with, and an account is given of the different methods of observation which have been employed. It is well that attention should have been re-directed to such investigations as that of Gerdien, who in 1905 used the method of electrical aspiration with remarkable results. This is only one of the many points awaiting further investigation when workers in the subject, attracted to it by such a book as this, become available in larger numbers.

In his critical and undogmatic treatment of atmospheric ionisation and kindred phenomena, Prof. Hess supplies just that stimulus which is necessary for the study of atmospheric electricity. There has been a tendency for work on this subject to fall into routine. Methods of observation seem to have suffered a premature standardisation. Observatories have been content to record readings of potential gradient and of conductivity and ion-counts made by this or that standard apparatus. Meanwhile no-one is very confident as to the precise meaning or value of some of these figures. We have no right to believe that things are so simple that we may expect to extract the truth from an accumulation of readings of a limited number of standard types of apparatus. In quite recent years, however, there have been evidences from many quarters of a new spirit of questioning about these matters. But many more investigations of atmospheric electrical phenomena are required of the kind which Prof. Hess has already carried out with success in Austria and which he is continuing at Heligoland.

No better introduction to the subject could be desired than that supplied by Prof. Hess. The presentation is so thorough and accurate that students of the subject will look forward with great interest to the larger work on atmospheric electricity which is being prepared by Prof. Hess in collaboration with his colleague, Prof. H. Benndorf, and which is planned to appear in 1931. Meanwhile it is to be hoped that the well-produced volume under review will have a wide circulation among English readers.

J. J. N.

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A BASIS FOR SEASONAL FORECASTING IN AUSTRALIA.

By H. A. HUNT, Commonwealth Meteorologist.

[Manuscript received February 2nd—Read April 17th, 1929.]

During the last few years a serious shortage of rain and grass in the pastoral areas of the interior of eastern Australia has again focussed attention upon the subject of seasonal forecasting. The possibility of achieving a measure of prescience in this field has proved a goal which has lured scientist and amateur alike to devote much time and patience towards the elucidation of the problem.

As the result of the many previous failures of meteorologists to establish weather cycles, I had become very sceptical of ever attaining to a workable method of forecasting by such methods. Close observation of Australian phenomena has, however, led me to the formulation of a theory that short cycles of about four years' duration do exist in our climatic variations, and that the cycle is a self-contained series of events depending upon the relation between temperature, rainfall and vegetation. It is the introduction of this new non-meteorological element—the vegetation—that I regard as an important if unconventional step in the elucidation of the weather cycle. But I wish first to draw attention to the circumstances which make Australia exert those heart-like pulsations that first attract and then repel the moisture-laden winds that bring the life-giving rainfall to the interior.

The most important fact of Australian meteorology is that the Continent lies in the southern high-pressure belt in the winter but is traversed through its tropical areas by the thermal equator in summer, and has, in consequence, a relatively dry interior and a much better watered seaboard, especially in the north and east. We may exclude as incomparable the desert of Gobi and the arid region of Turkistan, for although they lie under a winter anticyclone and a summer low pressure their temperatures are not those of the sub-tropical regions, and the deficiency of rainfall is largely due to the mountain barrier by which those areas are cut off from the tropical seas. Homoclimes of our interior are, therefore, restricted to the sub-tropical high-pressure belts, the outstanding example in respect to area and aridity being the Sahara-Arabia-Thar desert aggregate. The African section alone covers approximately 3,900,000 square miles, Arabia 1,150,000 square miles, and the Thar Desert 390,000 square miles, an aggregate of 5,440,000 square miles, compared with a similar region of 1,280,000 square miles in Australia, the criteria being average annual temperature over 70°F. and an annual rainfall of less than 10 inches.

Less extensive areas, but still of considerable economic importance, occupy the plateau region and part of the coast of western U.S.A., the Kalahari desert and adjacent country in the western part of South Africa and the centre of the narrow coastal plain between the Andes and the west coast of South America, including Atacama and the nitrate fields.

The Sahara undoubtedly must exert the major influence of its peculiar kind with Australia, second in extent and perhaps even more important since it is the scene of an effort to establish a great white race under tropical and sub-tropical conditions.

On account of their much lower specific heat, it is the continents rather than the oceans that exhibit most readily a response to solar influence, and by virtue of their locations disturb to a great extent the ideal distribution of solar climates.

Some idea of the energy involved in the exchanges between these continental areas and the surrounding seas may be gained from the knowledge that in January the pressure over Australia is about 6 millibars less than that over the sea in the same latitudes. To produce this pressure difference some 480,000 million (4.8×10^{11}) tons of air must have been removed from over the continent. The removal of this vast amount of air must be attributed to the greater heating of the continental air compared with that over the sea. As an index of this heating it may be stated that the maximum temperatures in January over the continent are about 20°F. (11°C.) greater than ocean temperatures in the same latitude. Probably at a height of about 2.75 kilometres the temperatures over land and ocean are much the same. The difference in the sensible heat content of the air over Australia and over an equal area of sea in the same latitudes has for its energy equivalent 47 billion (4.7×10^{13}) horse-power hours. This energy would be sufficient to provide power at the rate of 33 horse-power per acre throughout Australia for the month of January.

The Sahara, with an area of 7½ per cent. of the land surface of the globe and a range of 30°F. between the hottest and coldest months, is a great heat engine controlling the winds over neighbouring lands and seas and considerably modifying the general circulation of the atmosphere. The prevailing winds around this area are Northerly over southern Europe, and, except for a brief winter Westerly along the coast, over northern Africa, too. Over the west coast, including all the Niger basin, the indraught throughout the year is SW. to S. Inland over the Soudan the wind follows the sun, being Southerly in summer and Northerly in winter. Over the latter area there is considerable variability of seasons with alternation of famine and plenty, but the great heart of the Sahara appears to suffer a monotonous stability which is reflected as far away as western Europe. The prevailing moist Westerlies of north-west Europe become Northerlies in south-west Europe where the indraught of the great African furnace is felt. If the heat area changed in dimensions or intensity the resulting indraught would be expected to vary and consequently also the rainfall of western Europe. But while variation occurs in Europe and short, dry spells are defined as droughts, nothing comparable with the variations of north and east Australia and of the Soudan ever occurs in the Sahara.

In Australia the seasonal differences of pressure and wind circulation, temperature and rainfall, are more marked than in the Sahara, but superimposed upon this annual oscillation is a longer period of approximately four years. It is to the alternations during this short cycle that I have applied the simile of the heart or of a great lung taking deeper inspirations at short intervals of years and so bringing the heavier rains further into the interior.

The fundamental difference between the true desert region of the Sahara and the greater part of Australia's arid region is the lack of vegetation in the first case compared with the profusion of grasses that spring to life in the greater part of the Australian hinterland with the periodic arrival of the rain.

It is precisely this coming of the grasses that provides the mechanism of the automatic or terrestrial cycle of weather in Australia.

The sequence of observed events upon which I have based my theory is as follows:—

(*a*) In a dry summer the low humidities over the interior permit intense insolation. Some of this incoming solar heat is stored in the parched soil and some passes into the latent form as the result of the free evaporation from water surfaces and drying vegetation. The temperature of the air for some considerable height must be raised during this period.

(*b*) This temperature difference between the interior and the surrounding oceans causes a re-distribution of pressures which is followed by a great monsoonal indraught of moist oceanic air. In some years, such as 1928, a measure of this indraught is provided by the cooling effect of Southerly winds in the sub-tropics.

(*c*) In the early stages of the monsoonal inflow the accumulated heat of the interior is sufficient to keep the relative humidity low, to check cloud formation in low levels and to maintain a dry stratum of air below cloud drifts of coastal or oceanic origin.

(*d*) As the inflow proceeds, moisture accumulates, cloud develops, and insolation is reduced. At this stage occur the thunderstorms that herald the break of the dry spell, and widespread rains follow over the interior. Rapid evaporation follows the incidence of rain in the hot earth and absolute and relative amounts of moisture in the atmosphere are raised considerably over extensive areas. With this favourable supply of material further rains occur at short intervals of a week or two depending upon favourable pressure distributions and particularly upon the presence of a north to south trough over the eastern states. When such natural corridors are provided tropical moisture flows across to the southern seaboard and heavy thunderstorm rains occur inland.

(*e*) Shortly after the first rains have fallen in the interior grasses spring up and grow with marvellous rapidity. If the usual rains follow a carpet of rank grass is provided over the formerly parched land. The effect of this luxuriant vegetation is to shield the earth from further intense insolation, to check the loss of water by direct evaporation and to substitute the steady transpiration of moisture drawn from moderate depths by the plant roots.

The result of shielding the surface from insolation and withdrawing a large proportion of its water content is a general cooling of the earth. The water vapour passed into the air is a further check on insolation, and, being conducive to further rain formation, causes repetitions of the cycle of rainfall and evaporation or transpiration contributing to the gradual cooling of both earth and air throughout the interior of the continent.

(*f*) At the stage at which the continent is thoroughly cooled down but still clothed in the grasses, the monsoonal indraught is considerably weakened, and, lacking fresh supplies of oceanic moisture, rainfall diminishes, vegetation fails and the country assumes the dry condition favourable to intense insolation during the following summer season. This parching apparently goes on for a long time before the accumulation of heat is sufficient to induce the violent monsoonal indraught necessary to upset the arid phase of the cycle and introduce a fresh wet period.

(*g*) As a rule both the drying and warming of the earth and the subsequent wetting and cooling phases appear to extend over the period of one summer into the next. Precisely why this occurs when a normally dry cool winter period intervenes in each case, is not at all clear, but the length of the complete cycle, as shown by the weighted rainfalls of the eastern states, is normally four years. This period usually consists of two dry years followed by two wet years requiring two years to be allotted to the drying and heating phase and two to the wetting and cooling, unless these processes are sufficiently distinct to be allotted a year each in the following scheme :—

Year	1st	2nd	3rd	4th
Process	Drying	Heating	Wetting	Cooling
Rainfall	Low	Low	High	High

It has been towards the elucidation of the process involved in this apparently simple sequence that much investigation has been carried out.

RESULTS OF INVESTIGATIONS INTO THE SEQUENCE OF WET AND DRY SEASONS IN AUSTRALIA.

The outstanding result of these investigations was the establishment of a fairly definite four-year cycle which was most marked in the rainfall of the interior of Queensland and New South Wales, but is still evident in the weighted rainfall for the whole of these two states taken together with Victoria, comprising altogether the whole eastern portion of the continent. The western areas of Australia do not show such a regular alternation of wet and dry seasons.

In the tables below the years are shown coupled in pairs of which the aggregates for the 24 months make alternate wet and dry periods, although the single years do not always display higher or lower totals than each of the years in the opposing pair. Such a case is the year 1895, which belongs to the two wet years 1894-5, but is exceeded slightly by the rainfall of 1896, which belongs to the succeeding dry pair of years 1896-7. The uniform use of the calendar year may be partly responsible for this as it includes portions of two successive monsoon seasons.

Starting from 1888, when the Queensland data first became available, the pairs of high and low rainfall years alternate till, in 1902-3, which should be a high rainfall pair, the wet period is suppressed. The total for 1902-3 is still above that for the succeeding two years, and the sequence is not really broken till the pair 1914-5 provides a second low pair after the low years 1912-13. This double low period changes the phase of the cycle in much the same manner as the breaks at sunspot maximum change the phase of Braak's three-year cycle between Australia and the East Indies.

WEIGHTED MEAN ANNUAL RAINFALL, EASTERN AUSTRALIA (QUEENSLAND AND NEW SOUTH WALES).

Year.	Annual rainfall. in.	Mean of two years. in.	Character.	Year.	Annual rainfall. in.	Mean of two years. in.	Character.
1888	16.83	22.38	Dry	1908	23.66	23.71	Dry
1889	27.93			1909	23.77		
1890	37.20	36.22	Wet	1910	29.20	28.12	Wet
1891	35.24			1911	27.04		
1892	22.66	24.02	Dry	1912	19.70	22.98	Dry
1893	25.37			1913	26.27		
1894	36.23	29.99	Wet	1914	22.48	18.56	Dry†
1895	23.76			1915	14.65		
1896	25.52	22.81	Dry	1916	30.14	30.74	Wet
1897	20.11			1917	31.35		
1898	24.09	22.75	Wet*	1918	23.02	18.33	Dry
1899	21.42			1919	13.65		
1900	16.83	18.81	Dry	1920	28.46	29.41	Wet
1901	20.79			1921	30.36		
1902	12.44	20.53	Wet*	1922	20.20	18.39	Dry
1903	28.63			1923	16.58		
1904	22.77	20.00	Dry	1924	27.49	25.34	Wet
1905	17.22			1925	23.20		
1906	30.24	27.11	Wet	1926	17.32	20.35	Dry
1907	23.99			1927	23.48		

* Wet period suppressed but no change of phase.
† Change of phase in four-year cycle.

The four-year period in the rainfall is also fairly well marked in the percentage of the continental area over which the rainfall is above the average each year.

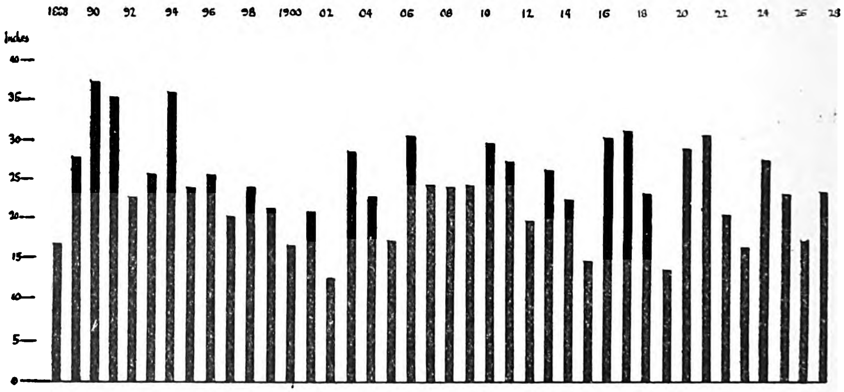

FIG. 1.—Queensland and New South Wales weighted Rainfall.

The following are the percentages :—

Year.	Area above average rainfall. %	Mean area two-year groups. %	Character.	Year.	Area above average rainfall. %	Mean area two-year groups. %	Character
1908	33	36.5	Dry	1918	28	20.5	Dry
1909	40			1919	13		
1910	75	50.0	Wet	1920	54	58.5	Wet
1911	25			1921	63		
1912	12	19.5	Dry	1922	21	21.5	Dry
1913	27			1923	22		
1914	11	18.5	Dry*	1924	27	25.5	Wet†
1915	26			1925	24		
1916	60	67.5	Wet	1926	21	27.5	Dry†
1917	75			1927	34		

* Change of phase.
† Doubtful change of phase.

These percentage areas are only a crude index of the relative proportions from year to year, because practice has varied with regard to the exclusion of the area in the western interior of the continent from which no rainfall reports are received.

CORRELATION OF RAINFALL AND TEMPERATURE IN THE AUSTRALIAN FOUR-YEAR CYCLE.

(Added June 4, 1929.)

Some remarkably high correlations have been discovered in the rainfall and temperature of the eastern interior of Australia. These coefficients are sufficiently high to prove the reality of the four-year cycle although the period 1913 to 1928 would be a short one to which to attach great importance if the values had been lower. This period covers the series since the change in phase of the four-year cycle.

For rainfall the average of nine districts in the interior of Queensland and the north-west of New South Wales was used.

The district means were not weighted for area in this calculation, but as the areas are of comparable size little error is introduced from this source.

For temperatures the means of seven stations well distributed over the same area were used. The quantities used for both rainfall and temperature were the means of three-month groups January to March; April to June; July to September; and October to December.

The highest correlation of all covers the period 1917 to 1928 when for eight pairs of values representing the rainfall July-September in one year and the rainfall January-March three and a half years later the coefficients were

$$r = .9416$$
$$\text{P.E.} = \pm .0267$$

The negative correlation for the half period is shown in two high coefficients.

For thirteen pairs of observations the temperature for October-December compared with the temperature for the same months two years later gave

$$r = -.7356$$
$$\text{P.E.} = \pm .0858$$

The twenty-one months' interval from the temperature of January-March to the temperature of October to December nearly two years later gives the negative correlation

$$r = -.8089$$
$$\text{P.E.} = \pm .0623$$

The remaining three correlations express the more intimate relationship between the temperature and the rainfall at short intervals. In this group the highest correlation pertains to the synchronous observations of temperature and rainfall in mid-summer, *i.e.*, January to March, where for sixteen pairs of observation

$$r = -.9139$$
$$\text{P.E.} = \pm .0277$$

Although this correlation does not distinguish between cause and effect since the data are synchronous, it is of interest in connection with the following.

The rainfall July-September compared with the temperature for the following October-December shows

$$r = -.6994$$
$$\text{P.E.} = \pm .0889$$

indicating that heavier winter or non-seasonal rains depress the spring temperatures.

The spring temperatures October-December then show a negative correlation with the following summer rain January to March when

$$r = -.81$$
$$\text{P.E.} = \pm .06$$

This last correlation indicates that a cooling down in spring, probably associated with the increasing humidity of the atmosphere, precedes bountiful summer rains.

DISCUSSION.

Mr. E. V. Newnham *(communicated):* I think Mr. Hunt has made out a good case for a four-year cycle in Australian weather, and it seems clear that such a cycle gives a promising starting point for an investigation into the possibility of seasonal forecasting. In regard to his theory that the springing into life of a profusion of grasses in the arid region, on the occurrence of rain after a prolonged drought, provides the mechanism for the cycle, I imagine that he has not yet had time in which to work out even the order of magnitude of the effects of such vegetation upon the temperature, wind and rainfall of Australia, and that the theory is put forward tentatively in order to direct attention to the possibility that it may provide a satisfactory explanation of the observed cycle. An obvious difficulty appears to my mind to lie in the fact that the arid region of Australia is dependent for its rainfall upon what Mr. Hunt describes as "deep inspirations" of moist tropical air, and is therefore probably dependent upon changes of the general circulation that are on too vast a scale to be appreciably affected by small modifications of the local heating of Australia. It may even be that two hemispheres are involved, as Dr. Simpson showed, in a paper read to this Society in 1921, to be the case for the rainfall of the Indian monsoon. It may be recalled that there is strong evidence that the rain-bearing south-westerlies of the Indian rainy season are diverted SE. trades from the southern hemisphere. It seems reasonable to suppose that the mere monsoonal indraught over Australia, resulting from abnormally high temperature due to clear skies in the interior, would normally fail to produce more than local orographical rain, in the same way that the inflow over north-west India fails to do so if the inflowing winds are not drawn from the appropriate far distant parts of the South Indian Ocean.

Apart from this general objection to the theory, there are probably detailed objections to the suggested effects of the grasses upon radiation, evaporation, temperature and finally rainfall, which, no doubt, other members of the audience will bring forward.

Mr. W. H. Pick said there was one curious point concerning Mr. Hunt's first table of rainfall periodicities that perhaps merited mention. Let the first year 1888 be omitted and the succeeding years be bracketed in couples, as 1889-90, 1891-92, and so on. Take the mean rainfalls of these new couples. The succession in this new form becomes a sequence of "wet-dry," "wet-dry," from 1889-90 to 1899-1900, followed by irregularities from 1901-02 to 1907-08, followed by another sequence of "wet-dry," "wet-dry" from 1909-10 to the end of the period taken by Mr. Hunt. It is true that the differences between wet and dry couples in this new series are not so marked as between Mr. Hunt's couples, but the change of phase that worried Mr. Hunt (see his couple 1914-15) is entirely absent. In short, the new series is not perhaps greatly inferior to Mr. Hunt's, for though Mr. Hunt, on his side, probably has his maxima and minima better placed, the new series, on its side, has avoided the worrying change of phase: but it does mean that in it alternate years fall into categories of different character from those into which they previously fell. Mr. Pick said that he himself could lay no claim either to being skilled in mathematics or versed in the intricacies of statistics, and he thought that it was likely that a mathematician or statistician could produce a ready explanation of the point he had raised.

Nevertheless, he felt that when such divergent results could be obtained by simply dropping the first year of the series the interpretations given by Mr. Hunt were vitiated to some extent for the average man. If the Queensland data had been available only from 1889 instead of from 1888 —a far from impossible hypothesis—it seems not unlikely that half of the succeeding individual years might have been placed in groups of different rainfall character from the ones to which Mr. Hunt had assigned them in his present paper.

Mr. A. J. **BAMFORD** said that he was very interested to hear of this four-year period in Australia, because he had recently been analysing the SW. monsoon rainfall of Ceylon and found distinct evidence of periods of 4.67 and 3.7 years, which meant that at times when the reinforcement showed most clearly, there was a period of approximately four years. The correlation between Australian and Ceylon variations seemed to be nearly inverse, but perhaps the most interesting point about it was that the years that stood out from the cycle in Australia tended to be abnormal years in Ceylon, too. Thus in 1899 and 1902, in which the Australian rainfall was below that suggested by the four-year cycle, the actual monsoon rainfall in Ceylon was a trifle above that suggested by the theoretical curves. A still more striking case was 1913, after which date the Australian series changed phase. The Ceylon floods of that year were exceptional; in fact, to find a parallel to 1913 we must go back to 1877, in which year Ceylon appears to have stolen much of India's monsoon, to the grave inconvenience of both parties. On the whole the parallelism seemed to point to the cause being world-wide rather than local.

Sir **DAVID BARKER** said he thought much light might be thrown on the subject of the paper by a study of the large anticyclonic areas. When he was in sailing ships it was customary to run the ship along the parallel in which the favourable winds were found, and this parallel shifted from time to time. The establishment of a meteorological station in the Antarctic regions and worked in conjunction with those in Asia would greatly assist in framing forecasts for future seasons. The matter was one of great importance to the Australian squatters.

Dr. C. E. P. **BROOKS** said that he was very interested in Mr. Bamford's remarks about the periodicity of rainfall in Ceylon, because he had just made a rough periodogram analysis of the rainfall values in Mr. Hunt's paper. The main periodicity appeared to be 3.7 years, which was a very common periodicity in meteorology, and he thought that there were also indications of a periodicity of between four and five years. From some work which he did on variations of rainfall in West Africa, he thought that these short periods probably resulted from local conditions, somewhat in the way described by Mr. Hunt, but controlled by some planetary or cosmical factor such as Sir Gilbert Walker's oscillations. When the local oscillation got out of step with the general oscillation, the periodicity broke down, starting again later, when circumstances were favourable, but not necessarily at the correct phase. Dr. Braak in Java had put forward somewhat similar ideas.

Mr. L. H. G. **DINES** said: With regard to the four-year period which Mr. Hunt has found, it seems probable that it is connected with a wider region than the continent of Australia alone. A four-year period maintained solely by processes occurring in Australia itself suggests the necessity for an enormous thermal inertia, which seems to be entirely beyond what one can imagine to exist. In England, under a period of sunny weather or during a frost, changes of ground temperature take place comparatively rapidly, and the times required seem much too small to be an effective cause of a four-year period. We have to remember also that the more heat that is received by day in clear weather the more is lost by radiation at night, which puts a limit to the capacity of the ground for storing solar heat.

Sir G. T. **WALKER** said that as the object in view was that of forecasting for individual years, not for pairs of years, the fundamental question was the existence of a period of four years. Further, as the existence of "chapters" was indicated, with liability to a complete reversal of phase, it was necessary in examining the periodicity to find the correlation coefficient r_4 between each year's rain and that four years before; the effect of a few chapters would not very seriously diminish r_4, though it might wipe out the Fourier amplitude. Calculation gave, with Hunt's figures, $r_4 = +.28$, $r_3 = +.18$, $r_2 = -.24$, $r_1 = +.08$, and from these we might deduce the regression equation :—

$$\text{Season's rain} = .11 \left\{\begin{array}{c}\text{rain}\\ \text{1 year}\\ \text{before}\end{array}\right\} - .22 \left\{\begin{array}{c}\text{rain}\\ \text{2 years}\\ \text{before}\end{array}\right\} + .21 \left\{\begin{array}{c}\text{rain}\\ \text{3 years}\\ \text{before}\end{array}\right\}$$

The resulting total correlation coefficient is .39, an amount which, though appreciable, is inadequate as a basis for forecasting. It happened that in 1910 the speaker had published in the *Indian Meteorological Memoirs* (Vol. XXI., Pt. 2) a short study on forecasting Australian rain as dependent on the southern oscillation. The resulting correlation coefficient was .61, and probably this could now be improved upon in view of the additional facts available. Sir G. T. Walker congratulated Australia warmly on having made a start with the publication of its seasonal rain and the study of the antecedent conditions.

Sir **RICHARD GREGORY** said: There have been many attempts to find cycles of rainfall or other factors of weather likely to be of service in forecasting seasonal conditions, and from a practical point of view something can be said in favour of them. Even if the forecasting cannot always be correct, but has a two to one, or three to one, chance in its favour, it may be of service, and Mr. Hunt's four-year sequence certainly seems to have this advantage. Australia apparently lends itself to such long-range forecasting, for I remember that the late Dr. H. C. Russell gave much attention to this, and showed that for 180 years preceding 1896 there had been droughts in New South Wales every 19 years, and he went so far as to time their period back to the time of Joshua. Sir Norman and Dr. W. J. Lockyer showed that there was a relation between Indian and Australian pressures and rainfall, and this result is worth consideration in connection with Mr. Hunt's paper.

Mr. A. **PEARSE JENKIN** (*communicated*): In the *Quarterly Journal of the Royal Meteorological Society* Vol. XXXIX., No. 165, January, 1913, I arranged the yearly rainfall of a number of places in Europe, in periods of three years: and if the figures for Australia, given by Mr. Hunt, are arranged in the same way, very similar results are obtained, the figures being much like those for Greenwich, given in my paper.

The following table gives the result of this arrangement :—

First year of 3 year periods.	Rainfall in inches.			Summary of Chapters.		
	1st year.	2nd year.	3rd year.	1.	2.	3.
1888	16.8	27.9	37.2			
1891	35.2	22.6	25.4			
1894	36.2	23.8	25.5			
1897	20.1	24.1	21.4			
1900	16.8	20.8	12.4			
1903	28.6	22.8	17.2			
1906	30.2	24.0	23.4	167.1	138.1	125.3
				27.8	23.0	20.9 Average.
1909	23.4	29.2	27.0			
1912	19.7	26.3	22.5			
1915	14.6	30.1	31.3			
1918	23.0	13.6	28.5	80.7	99.2	109.3
				20.2	24.8	27.3 Average.
1921	30.4	20.2	16.6			
1924	27.5	23.2	17.3			
1927	(23.5)					
	322.5	308.6	305.7			

It will be noted that a " chapter " appears to end with 1890. From 1891 to 1908, amounting to six three-year periods, the periodicity is very well marked, and so it is for the years 1909 to 1920 (four three-year periods), but there is very marked reversal. In 1921 a new series of reversed values appears to begin, and for the first two three-year periods to which the table extends the periodicity is very well marked.

Mr. H. A. HUNT in a reply writes: It is a pleasure to an author so far removed from the centre of discussion to see by the interest evinced that many of the speakers must have agreed with Sir Richard Gregory and myself in considering Australia an excellent field for the study of seasonal forecasting. It was precisely to overcome the necessity for an enormous thermal inertia which Mr. L. H. G. Dines advances as an objection to a period as long as four years that the complementary effect of vegetation was introduced. In their absence during the hot part of the cycle grasses, of course, play no part in the accumulation of heat, but during the well grassed period following the rain the presence of transpiring vegetation is an important factor in more effectively cooling the earth and consequently increasing the amplitude of temperature variations in the soil. This is shown by more severe frosts near growing crops.

It appears to me paradoxical to accept the facts concerning the great Asiatic monsoons, which constitute a major disturbance of the normal planetary distribution of climate, while denying to a sea-girt land mass the size of Australia a similar monsoonal interchange on a grand scale. Probably no other continent shows such a complete cyclonic circulation around the heated interior in summer and so well marked an anticyclonic outflow across all coasts in the winter. These effects can only be related to the condition of the continent itself. Superimposed upon these annual changes are the variations from vegetation to aridity which modify the condition from year to year providing *in situ* a factor stronger than any other single and more remote cause of seasonal variations in Australia. I had hoped that this very important aspect of the matter would have received more attention in the discussion, particularly as most of the points raised by other speakers can be dealt with by reference to the supplementary section of the paper containing correlations of temperature and rainfall over the eastern interior of the continent.

Dr. Brooks's suggestion that West African rainfall appeared to vary in short cycles, which he was inclined to attribute to local conditions (in the continental sense), is very important. I had always hoped that the African continent would supply some supporting evidence. Mr. Bamford's experiences were also particularly interesting, since Ceylon appeared to bear out the short Australian period. The latter, however, did not appear to be the 3.7 years suggested by these two gentlemen. Using the monthly data for the inland districts of Queensland and New South Wales I found the correlation of 3.5 years much more marked than any other, the coefficient for July-September rainfall in one year with January-March rainfall three and a half years later being $r=0.94$ and P.E. $= \pm 0.027$. The negative correlation for the half period is best for temperature $r=-0.74$ and P.E. $= \pm 0.086$ for January-March and October-December twenty-one months later.

Since these data refer only to the lowland interior they dispose of Mr. Newnham's suggestion that the monsoonal effect would be chiefly noticeable as orographical rains, which in Australia are confined chiefly to coastal districts. These correlations also clear up the issue raised by Sir Gilbert Walker, and give precision to estimates for particular seasons —a step further than his demand for annual amounts of rainfall. Mr. Pick was in error in thinking that the accident of the commencing date influenced the choice of the cycle. A glance at the graph would dispose of this contention. I fail to see why a series with a smaller amplitude in the cycle and a consecutive series of four discordant pairs should be advanced in preference to my series with a single reversal of phase. Mr. A. Pearse Jenkins' "chapters" are certainly very interesting, but suffer the disability of frequent changes of phase in the short cycle.

Messrs. C. F. Casella & Co.

We are asked to announce that Messrs. C. F. Casella & Co., Ltd., scientific instrument makers, have removed into larger premises at Regent House, Southampton Street, Fitzroy Square, London, W.1.

The New Captain-Superintendent of H.M.S. *Worcester*.

Lieut.-Commander G. C. Steele, V.C., R.N., who is a Fellow of this Society, has been appointed Captain-Superintendent of H.M.S. *Worcester*, the Thames Nautical Training College. Captain Steele has thus risen to the command of the vessel in which he began his sea career as a cadet. He served in the Mercantile Marine before the war, and during the war he had varied experience in the Royal Navy—in submarines, Q ships, and in H.M.S. *Royal Oak* at the Battle of Jutland. He won the Victoria Cross in command of a coastal motor boat in the raid on Kronstadt Harbour in August, 1919.

Another Fellow of this Society has held the command of H.M.S. *Worcester*, Captain Sir David W. Barker was Captain-Superintendent for nearly 30 years, from 1892-1919.

THE INDEX OF REFRACTION OF DAMP AIR AND OPTICAL DETERMINATION OF THE LAPSE-RATE.

By D. BRUNT, M.A., B.Sc.

[Manuscript received March 20—Read May 15, 1929.]

Following a suggestion made by Whipple[1] an attempt was made by Johnson and Roberts[2] to devise an optical method of measuring the lapse-rate of temperature by observing the markings on a vertical scale through a fixed telescope. The curvature of the path of a ray was assumed to depend upon the vertical gradient of density. It recently occurred to me that the curvature gives a measure of the gradient of "optical density," which may differ from the gradient of density on account of the presence of water vapour in the atmosphere. A brief account is given below of the effect upon the index of refraction of air produced by the presence of water vapour.

A very simple relation between the index of refraction and density for a given substance was given by Gladstone and Dale[3]:—

$$\frac{\mu-1}{\rho}=\text{constant} \quad . \quad . \quad . \qquad (1)$$

If the value of μ be known for any density, then by the use of this relation, the value of μ for any other density is readily computed. Alternatives to Gladstone and Dale's law are Jamin's formula[4]

$$\frac{\mu^2-1}{\rho}=\text{constant} \quad . \quad . \quad . \qquad (2)$$

and Lorentz's formula[5]

$$\frac{\mu^2-1}{(\mu^2+2)\,\rho}=\text{constant} \quad . \quad . \quad . \qquad (3)$$

A discussion of the application of these formulæ to various liquids was given by Gale.[6] We shall only be concerned here with the indices of refraction of gases, for which μ is so nearly equal to unity that any data which are used to confirm equation (1) may be regarded equally well as confirming equations (2) and (3). A recent investigation by Pérard[7] of the dependence of μ on temperature and pressure indicates that at ordinary atmospheric pressures Gladstone and Dale's law is followed very closely.

Pérard's formula is (for dry air free from CO_2)

$$(\mu-1)\,10^6=\left(288{\cdot}02+\frac{1{\cdot}482}{\lambda^2}+\frac{0{\cdot}0309}{\lambda^4}\right)\frac{h\,(1+\beta h)}{760\,(1+760\,\beta)}\,\frac{1}{1+0{\cdot}003716\,\theta}$$

where λ is the wave length in microns, h is the pressure in millimetres, θ is the temperature in degrees centigrade, and

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[1] Dictionary of Applied Physics, Vol. III. Atmospheric Optics, p. 519.

[2] *Q.J.R. Meteor. Soc.*, **51**, 1925, p. 131.

[3] *Phil. Trans. R. Soc.*, 1863, p. 317.

[4] *Ann. chim. phys., Paris* (3e Serie), **52**, 1858, p. 163.

[5] *Wiedemann's Ann. Physik.*, **9**, 1880, p. 641.

[6] *Physical Review*, **14**, 1902, pp. 1-16.

[7] *Comptes Rendus*, **180**, 1925, p. 49.

$\beta = 2{\cdot}4 \times 10^{-6}$. For pressures which are approximately atmospheric, we may neglect β, and the formula then reduces approximately to Gladstone and Dale's formula.

The index of refraction of a mixture of substances which have no chemical action on each other is readily deduced from Gladstone and Dale's law. If V_1, V_2, be the volumes, μ_1, μ_2, the indices of refraction of the components of the mixture, and V and μ be the corresponding quantities for the mixture, then[8]

$$\mu - 1 = (\mu_1 - 1)\frac{V_1}{V} + (\mu_2 - 1)\frac{V_2}{V} \quad . \quad . \quad . \quad (4)$$

The equation may be extended to take account of any number of components. Experiment has shown that this law is fulfilled by mixtures of liquids. If it is applied to compute the index of refraction of dry air, regarded as made up of 78 per cent nitrogen, 21 per cent oxygen, and 1 per cent argon, we find $\mu = 1{\cdot}0002916$, which compares favourably with the experimental[9] value 1·0002918.

We may regard damp air as a mixture of dry air and water vapour in the relative proportions by volume of $p-e$ and e, where p is the total pressure and e the vapour pressure. If μ_1 be the index of refraction of dry air, and μ_2 the index of refraction of water vapour, and μ the index of refraction of the damp air formed by mixing them, then

$$p\,(\mu - 1) = (p - e)\,(\mu_1 - 1) + e\,(\mu_2 - 1)$$

$$\text{or } \mu = \mu_1 - \frac{e}{p}(\mu_1 - \mu_2) \quad . \quad . \quad . \quad . \quad (5)$$

The value of μ derived from this equation is appropriate to a mixture of dry air and water vapour in the relative proportions $p-e$ and e at a temperature of 0°C. and 760 mm. (1013·23 mb.), these being the standard conditions for which indices of refraction are usually given. Calling these standard conditions T_0 and p_0, we can at once write down an expression for the index of refraction for damp air at temperature T, pressure p, and vapour pressure e, in the form

$$\mu - 1 = \frac{pT_0}{p_0T}\left\{\mu_1 - 1 - \frac{e}{p}(\mu_1 - \mu_2)\right\} \quad . \quad . \quad . \quad (6)$$

For the D line of sodium Kaye and Laby's tables give

$$\mu_1 = 1{\cdot}000292\,;\ \mu_2 = 1{\cdot}000257.$$

Hence (6) becomes

$$\mu - 1 = \frac{pT_0}{p_0T}\left\{0{\cdot}000292 - 0{\cdot}000035\frac{e}{p}\right\}. \quad . \quad . \quad (7)$$

For dry air with $e=0$, it is readily shown from equation (7) that if $d\mu$ is the change in the value of μ when T is increased by 1°C., the pressure remaining constant, then

$$\frac{d\mu}{\mu - 1} = -\frac{dT}{T} = -\frac{1}{T}$$

$$\text{and } d\mu = -0{\cdot}000292/T = -1{\cdot}0 \times 10^{-6}$$

at ordinary atmospheric temperatures.

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[8] *Vide* Preston's Theory of Light. Chapter VI.

[9] Kaye and Laby's Tables, 1911, p. 71.

In the small table which follows, the value of $10^6 \times 0·000035\, e/p$ is given for a range of temperatures, taking e to be the saturation vapour pressure, and taking $p = 1000$ mb.

T	273	283	288	293	298	303
e/p	0·006	0·012	0·017	0·023	0·032	0·042
$10^6 \times 0·000035\, e/p$..	0·21	0·42	0·60	0·81	1·12	1·47

This table may be interpreted as follows. Air which is saturated at 288a. has the same index of refraction as dry air at a temperature of 288·6a. Thus in air at a temperature of 288a. the optical effect of a change from saturation to five-sixths saturation is the same as that of a change of 0·1°C.; or to look at it in another way, a refraction effect which might be interpreted as due to a lapse-rate of 2°C./100 metres might be due to a lapse-rate of relative humidity at the rate of 33 per cent per 10 metres. It will be noted that the effect of humidity may be considerable at very high temperatures, at which the vapour pressure becomes relatively great.

Refraction and Density of Damp Air.

The density of damp air is readily found to be $A(p - \frac{3}{8}e)/T$ where A is a numerical constant. This may also be written Ap/T' where T' is the virtual temperature. T' is related to T by the equation

$$T' = T \Big/ \left(1 - \tfrac{3}{8}\frac{e}{p}\right) = T\left(1 + \tfrac{3}{8}\frac{e}{p}\right) \text{ approximately} \quad . \qquad (8)$$

For air saturated at 288a., $T' = 288 + 1·9$. Thus air saturated at 288a. would have the same density as dry air at the same pressure, but at a temperature of 289·9a., and would have the same index of refraction as dry air at a temperature of 288·6a., with the same pressure. If T'' is the temperature of dry air whose index of refraction is the same as that of the damp air at temperature T, then we find from equation (7)

$$\mu - 1 = \frac{Bp}{T}\left(1 - \frac{35}{292}\frac{e}{p}\right) = \frac{Bp}{T''} \quad \text{where } B \text{ is a constant.}$$

Hence $$T'' = T\left(1 + \frac{35}{292}\frac{e}{p}\right) \text{ approximately}$$

or $$T'' = T\left(1 + \tfrac{1}{8}\frac{e}{p}\right) \quad .$$

with sufficient accuracy for our purpose.

Hence

$$T'' - T = \tfrac{1}{3}(T' - T) \quad . \quad . \quad . \quad . \qquad (9)$$

By means of this equation we can readily compute T'' using the extensive tables of virtual temperature T' which are available.

The following artificial example shows how equation (9) can be usefully employed. Let the temperature and relative humidity at 1 metre above the ground be 288a. and 85 per cent respectively, and let both factors decrease uniformly, to 287·5a. and 70 per cent respectively, at 3 metres above the ground. The virtual temperature T' decreases by 0·88°C. within the range of 2 metres. Hence

$$\frac{dT'}{dz} = -\frac{0{\cdot}88}{200} = -0{\cdot}0044^\circ\text{C./cm.}$$

$$\frac{dT}{dz} = -\frac{0{\cdot}5}{200} = -0{\cdot}0025^\circ\text{C./cm.}$$

Differentiating equation (9) and applying the above results, we find

$$\frac{dT''}{dz} = \tfrac{2}{3}\frac{dT}{dz} + \tfrac{1}{3}\frac{dT'}{dz} = -0{\cdot}0031^\circ\text{C./cm.}$$

Thus the optical estimate of the lapse-rate would be 0·31°C./metre as compared with the true lapse-rate of 0·25°C./metre, giving an error in the estimated lapse-rate of 0·06°C./metre. The errors in the optical estimates of lapse-rate in the experiments of Johnson and Roberts were on the average about 0·1°C./metre, or almost double the error which would be produced by a diminution of relative humidity by 15 per cent in 2 metres at the temperatures of the example considered above. Humidity was not measured in the course of the work of Johnson and Roberts and so it is not possible to estimate the extent to which variations of humidity were responsible for the spread of their estimated lapse-rates from the observed values.

ASTRONOMICAL REFRACTION.

It is shown in any standard text-book on astronomy that the effect of refraction is to elevate a star whose true zenith distance is Z through an angle $(\mu - 1) \tan Z$. For dry air under standard conditions this angle is ζ, where

$$\zeta = 60{\cdot}6'' \tan Z.$$

The correction for water vapour is small, and probably not of serious importance unless the temperature is high and the air nearly saturated. For air at 303a. the saturation vapour pressure is 43 mb., and the correction to $\mu - 1$ is given by equation (7). If we assume the pressure to be standard pressure p_0, then

$$\begin{aligned} 10^6 (\mu - 1) &= \frac{292 \times 273}{303} - 35 \times 0{\cdot}043 \\ &= 263{\cdot}2 - 1{\cdot}5 \\ &= 261{\cdot}7 \end{aligned}$$

The effect of water vapour alone is to diminish $\mu - 1$ by approximately 0·6 per cent of its value, and to diminish the angle ζ by $0{\cdot}31'' \tan Z$. This may be quite appreciable when the star is low. It is probable that similar errors also arise in survey work, and that the effect of water vapour on the refractive index of air is responsible for some of the anomalies observed in measuring the dip of the horizon. In a discussion of the observations of dip of the horizon made on the *Galilee* and the *Carnegie*, W. J. Peters[10] cited a number of cases of abnormal dip which could not be explained merely by the effect of temperature variations in the vertical. The unexplained residual errors are in the direction which would be anticipated if they were due to water vapour.

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[10] *Terr. Mag., Washington*, **23**, 1918, pp. 47-61.

The effect of water vapour in the atmosphere upon the accuracy of survey work has been commented upon by Boccara[11], but I have not been able to consult his paper.

Since first writing this paper I have found that Lorentz[12] gave the equivalent of equation (7) above. Lorentz's correction to μ was $-0{\cdot}000041\ e/p$, the difference in the numerical coefficient being due to the difference in the values assumed for the coefficient of refraction of water vapour. The value of μ for water vapour quoted from Kaye and Laby's tables is Mascart's determination (1·000257), but Lorentz's own determination was 1·000250. The discordance between the different determinations of μ for water vapour is rather great, and though Mascart's value has been adopted in the present paper the writer is not confident that this is in any sense a final value. It should also be noted that Lorentz's formula for correcting μ for water vapour is quoted in the Smithsonian Physical Tables (1921), p. 293, but with an error in sign.

I am much indebted to one of the referees of the Society who brought to my notice a number of the papers to which reference has been made above.

DISCUSSION.

Sir RICHARD GREGORY said: Though on a particular day the gradient of optical density of air may be used to measure the lapse rate of temperature, yet it is obviously an integrated effect, and several factors may enter into it. Mr. Brunt has provided us with a useful physical discussion of the effect of humidity on the variation of optical density, and his results should be considered in connection with further observations of the gradient of density as a measure of lapse rate of temperature, and of refraction of dry and damp air.

Typhoons and Hot Weather in Hongkong.

There is an idea prevalent in Hongkong that a period of a few hot days in summer or autumn is frequently followed by a typhoon. Mr. L. Gibbs has made an investigation with a view to ascertaining whether there is sufficient truth in this idea for it to be of use in forecasting typhoons.

The data available were the hourly values of pressure, temperature, wind velocity, and direction, and the tracks of the typhoons of the Far East, published by the Royal Hongkong Observatory since its opening in 1884. Mr. Gibbs chose the 36 years 1884-1919 for his investigation, and he also made use of the 30-year normals for 1884-1913. The Observatory defines "typhoon force" as 80 miles an hour with the old factor 3 or 59 miles an hour with factor 2.2, and a typhoon gale as 48 miles an hour (or 35 miles an hour with factor 2.2). The following investigations were made:—

1. Periods of four days any three days of which had maximum tem-

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[11] *Nuovo Cimento, Pisa*, **2**, 1901, pp. 204-211.
[12] *Wiedemann's Ann. Physik.*, **11**, 1880, p. 91.

peratures of 90°F. and over were considered as "hot spells," and the typhoons following within a week of these hot spells were counted.

2. A five-day period whose mean temperature was more than 2°F. above the corresponding normal, as given by the five-day normals published by the Observatory, was called a "hot period"; the typhoons occurring within a week of the last day of "hot periods" were counted.

3. The mean temperatures of two days and four days preceding recorded typhoons were compared with the corresponding 30-year normals.

The first two investigations gave results of no value for forecasting, but the third investigation showed that, except perhaps in July, there is a general tendency for temperature two and four days before a typhoon to be above normal, the tendency appearing to become more marked as the season advances. The following tabular statement summarises the results; it gives the average net excess over the normal in °F. of days preceding a typhoon gale of 60 miles an hour (factor 3) and upwards:—

July—previous 4 days nil; previous 2 days .28.
August—previous 4 days .37; previous 2 days .97.
September—previous 4 days 1.18; previous 2 days 1.30.
October—previous 4 days 3.36; previous 2 days 4.24.
November*—previous 4 days 2.60; previous 2 days 2.90.

Discussions at the Meteorological Office.

The meetings for the discussion of recent contributions to meteorological literature will be resumed at the Meteorological Office during the session 1929-30. The meetings will be held on alternate Mondays, promptly at 5 p.m., beginning on Monday, 14th October, 1929. Tea will be available from 4.30 p.m. The dates and subjects for discussion are as follows:—

October 14th.—Opener, Colonel E. GOLD. On the properties of sea ice, by FINN MALMGREN. Norwegian North Polar Expedition with the *Maud*, 1918-25. *Scientific Results*, Vol. **I.**, No. 5, Bergen, 1927.

October 28th.—Opener, Captain F. ENTWISTLE. Fog and haze, their causes, distribution and forecasting, by H. C. WILLETT. *Monthly Weather Review*, **56**, 1928, pp. 435-468.

November 11th.—Opener, Mr. J. E. BELASCO. On the exposure of thermometers in Ceylon, by A. J. BAMFORD. *Colombo, Ceylon J. Sci.*, (Sec. E) *Bull.*, I., 1928, pp. 153-167, pls. 3.

November 25th.—Opener, Mr. S. F. WITCOMBE. The regeneration of a depression over the North Sea and Baltic Sea (analysis of the weather during the period 29th September to 3rd October, 1912), by RICHARD SCHRÖDER. *Leipzig, Geophys. Inst. Univ., Veroff.* (2 Ser.) Bd. **4**, Heft 2, 1929, pp. 49-116. (In German).

December 9th.—Opener, Mr. H. W. L. ABSALOM. A theory of auroras and magnetic storms, by H. B. MARIS and E. O. HULBERT. *Physic. Rev., Minneapolis, Minn.*, **33**, 1929, pp. 412-431.

The dates for the subsequent meetings are as follows:—1930, January 13th and 27th, February 10th and 24th, and March 10th.

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* Only one observation.

THE INFLUENCE OF SMOKE AND HOT GASES FROM FACTORY CHIMNEYS ON RAINFALL.

By J. R. ASHWORTH, D.Sc.

[Manuscript received March 25—Read May 15, 1929.]

In an investigation on atmospheric pollution extending over a number of years, it became necessary to examine the rainfall on Sundays, when pollution was a minimum, with the rainfall of other days of the week, and it was accidentally discovered that Sunday was the day of the week with least rain. The subject was then more fully investigated, and it now appears that the lesser rainfall of Sunday may reasonably be attributed to the lesser emission on that day of the week of smoke and hot gases from mill chimneys.

In a confined manufacturing area, such as the town of Rochdale, with a large number of factories burning quantities of coal of the order of 500 to 1,000 tons a day, it is not unlikely that the volume of heated gases which rises is sufficient to give that uplift to the atmosphere which is required to provoke an increase of rain. It has been shown by Dr. H. R. Mill that a slight uplift to the air, such as is caused by the passage of the wind over a small elevation of the land in a flat country, immediately augments precipitation of rain. This effect of an uplift to the air may be looked for over a collection of mill chimneys from which a considerable upward current of hot gases issues for a third to a half of the 24 hours. There is also the probability that the fine flue dust ejected by the draught up the chimney may supply an abundance of the nuclei which promote the formation of rain, and further, there may possibly be some similar effect as a result of the ionisation of the gases which accompanies combustion.

It is not to be expected that the effect will be a large one, but the numerical data which follow seem to point to its reality.

ANNUAL RAINFALL.

An interval of 10 years from 1918 to 1927 inclusive was first examined for annual rainfall in Rochdale for each day of the week. Sunday showed itself the day of least rainfall when the average was taken and Monday the day of largest rainfall. The Sunday average per annum is 6·06 inches. The average per annum of 1/7th of all the days of the week is $6{\cdot}95 \pm 0{\cdot}18$ inches. The ratio of the Sunday average to 1/7th the average of all the days of the week is $6{\cdot}06/6{\cdot}95 = 0{\cdot}87$. This means that Sunday has a rainfall 13 per cent. less than the average per day of all days.

The record at Stonyhurst for the same ten years was then examined to see if the rainfall in a place having similar geographical and meteorological features, but with factories at a distance from it and with less smoke, would yield a different or modified result. Here the average for the Sunday rainfall per annum is 6·66 inches, and for 1/7th of all days $7{\cdot}11 \pm 0{\cdot}20$. The ratio of Sunday to all days is $6{\cdot}66/7{\cdot}11 = 0{\cdot}94$. The deficiency on Sunday is here only

6 per cent., and further, Sunday is not the day of least rainfall, although not much in excess of Friday, which is the least. Briefly, Sundays and week-days at Stonyhurst do not differ so much from each other as at Rochdale.

Ten years is a period, which, while long enough for comparison in this case, is not long enough to establish conclusively a deficiency of rain on Sundays, or, more correctly, an excess of rain on week-days, and the inquiry was therefore extended to cover 30 years from 1898 to 1927 inclusive. In this longer period we find at Rochdale the Sunday annual average to be 6·17 inches and 1/7th of the annual average of all days of the week, 6·54± 0·106. The ratio of Sundays to all days is 6·17/6·54=0·94

TABLE I.—RAINFALL ON EACH DAY OF THE WEEK FOR 30 YEARS AT ROCHDALE.

Year.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Total.
1927	6.01	6.92	5.96	8.50	5.34	6.61	10.67	50.01
1926	7.13	8.10	6.07	6.00	5.61	7.34	6.06	46.31
1925	2.92	10.76	7.42	6.53	6.08	5.19	6.54	45.44
1924	8.00	6.99	6.01	5.35	5.87	7.00	8.12	47.34
1923	5.63	10.39	11.41	5.62	9.09	8.09	6.83	57.06
1922	5.47	6.67	5.47	8.92	6.24	5.26	5.66	43.69
1921	4.54	7.92	6.82	5.59	5.66	5.58	6.33	42.44
1920	6.30	6.56	6.86	8.39	9.79	7.37	7.67	52.94
1919	4.93	9.48	6.09	7.33	6.45	4.99	4.40	43.67
1918	9.71	9.26	6.10	8.94	8.29	7.47	7.86	57.63
Aver. of ten years	6.064	8.305	6.821	7.117	6.842	6.490	7.014	48.653
1917	6.82	6.50	5.86	6.32	6.57	6.91	7.43	46.41
1916	9.30	5.52	4.25	6.26	8.61	6.30	5.90	46.14
1915	5.99	5.62	8.20	5.67	4.56	9.71	5.68	45.43
1914	7.64	5.38	5.80	5.57	8.98	6.56	7.43	47.36
1913	4.24	4.90	6.11	4.24	6.66	6.89	6.43	39.47
1912	7.61	8.33	8.11	8.12	6.08	5.16	8.46	51.87
1911	6.86	4.54	6.72	5.79	5.85	5.78	6.42	41.96
1910	8.90	7.43	7.66	6.75	6.95	5.22	6.93	49.84
1909	6.67	6.83	7.35	5.21	8.72	6.48	7.31	48.57
1908	6 78	5.06	5.80	6.95	7.86	3.39	5.44	41.28
1907	5.29	4.75	7.79	8.94	6.02	7.04	7.37	47.20
1906	6.25	5.93	5.23	9.65	7.71	6.30	7.47	48.54
1905	4.80	4.44	5.43	5.27	4.84	5.26	7.03	37.07
1904	5.07	6.06	5.58	6.46	4.55	5.01	3.70	36.43
1903	5.81	8.66	10.31	6.32	8.18	7.61	6.78	53.67
1902	4.22	6.48	4.39	4.00	4.11	5.14	3.91	32.25
1901	4.08	7.36	6.96	4.83	5.85	3.05	6.55	38.68
1900	6.59	8.33	6.35	6.74	8.62	8.12	7.97	52.72
1899	6.54	6.16	5.57	4.67	5.07	8.03	4.99	41.03
1898	4.87	6.04	8.79	5.75	5.20	5.13	5.68	41.46
Aver. of 30 years	6.166	6.879	6.682	6.489	6.647	6.266	6.634	45.797

which is a Sunday deficiency of 6 per cent. Sunday again on the average of this 30 years is the day of least rain, followed rather closely by Friday, whilst Monday is the day of highest rainfall (Fig. 1). The difference between the all-days and Sunday average of 0·37 inch is more than three times the probable error. Tables I. and II. subjoined give the rainfall for each day of the week for each year both at Stonyhurst* and Rochdale.

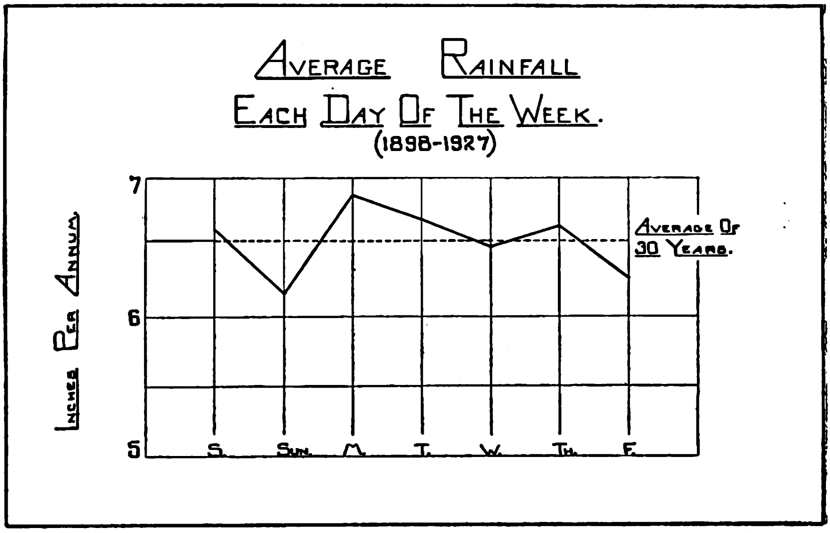

FIG. 1.

TABLE II.—RAINFALL ON EACH DAY OF THE WEEK FOR 10 YEARS AT STONYHURST

Year.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Total.
1927	5.20	6.63	8.08	10.41	6.26	4.30	10.68	51.56
1926	8.93	6.50	6.25	8.35	7.38	5.65	5.72	48.78
1925	2.50	7.33	6.81	7.19	5.94	5.89	5.40	41.06
1924	9.66	7.44	5.80	6.24	5.07	6.12	10.43	50.76
1923	6.71	13.00	11.31	7.89	7.36	10.40	7.43	64.10
1922	6.50	7.21	6.32	9.10	6.30	6.02	5.68	47.13
1921	4.72	9.92	5.64	7.66	6.64	5.87	8.04	48.49
1920	5.78	6.35	5.43	7.62	6.96	6.95	6.75	45.84
1919	4.15	8.44	5.59	6.30	8.72	4.49	3.39	41.08
1918	12.49	8.37	6.92	8.60	7.01	7.21	8.02	58.62
Aver. of 10 years	6.664	8.119	6.815	7.936	6.764	6.290	7.154	49.742

In passing, it may be noticed that in the 30 years under review at Rochdale, the rainfall has been steadily increasing from the annual average of 42·81 inches in the first ten years to 45·83 in the next ten years and to 48·65 in the last ten years, ending with the year 1927.

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* I am indebted to the Director of the Stonyhurst College Observatory for kindly supplying the data for Table II.

HOURS OF RAINFALL.

If the emission of volumes of hot gases from factory chimneys has any influence on rainfall it ought to show itself by an enhanced rainfall during the working hours of the day-time, when the discharge from the chimneys is most active, compared with the quiescent hours of the night. Sundays and week-days also should show some difference in the hours of rain.

It is only for the last two years that a continuous record of rainfall in Rochdale has been kept by means of a self-recording rain gauge, and although this is rather a short period it is long enough to allow definite results to be deduced. During this time the sum of all rainy intervals of not less than 15 minutes' duration for each hour of the twenty-four has been obtained for the total of all days of the week and separately for Sunday. Table III.

TABLE III.—NUMBER OF HOURS OF RAIN, 1926–28.

Hour of the Day or Night.	Total for All Days.	Total for Sundays multiplied by 7.
1	58.50	63.00
2	58.00	56.00
3	60.50	64.75
4	63.50	70.00
5	67.00	70.00
6	65.75	80.50
7	74.25	80.50
8	77.50	70.00
9	82.25	73.50
10	84.75	77.00
11	73.00	45.50
12	58.00	38.50
13	60.50	35.00
14	71.50	47.25
15	75.25	61.25
16	79.50	73.50
17	76.25	66.50
18	69.75	73.50
19	76.50	84.00
20	76.50	71.75
21	71.25	71.75
22	62.75	77.00
23	55.00	71.75
24	60.00	84.00
Total ...	1657.75	1606.50
Night ...	775.25	864.50
Day ...	882.50	742.00

The period of two years comprises 12 winter months and 10 summer months.

gives a complete account of the whole of the observations, but the results are more readily appreciated by consulting Fig. 2, which exhibits the curve of rainy hours for all days (which is nearly the same as for week-days only) and a curve for Sundays. It should be stated that the rainy hours for Sundays are plotted on a sevenfold scale in order to make them comparable with the rainy hours of the whole of the seven days of the week. It will be seen that the latter, represented by the full line, are in excess of the Sunday rainy hours from about 7.0 a.m. to 6.0 p.m., an interval which closely corresponds to the working hours of week-days. Of the 1,657 hours of rain, 882 were in the daytime, that is, from 6.0 a.m. to 6.0 p.m., and 775 at night. The ratio of the day to the night hours of rain is

$$\frac{\text{Day}}{\text{Night}}=\frac{882}{775}=1\cdot14$$

which shows a daytime excess of 14 per cent.

On Sundays the ratio of the day to the night hours of rain is

$$\frac{\text{Day}}{\text{Night}}=\frac{106}{123\cdot5}=0\cdot86.$$

Here there is a complete reversal, and the night hours are in excess of the day hours of rain by 14 per cent. This last result is in conformity with Stonyhurst where the night rain is more than the day rain, the ratio of day to night being 0·92, as the average of 20 years. Thus on Sundays at Rochdale there is a distribution of the hours of rainfall, over the 24 hours, like Stonyhurst and other west coast stations, but the week-day distribution suggests that the normal course of events has been disturbed so as to make the hours of rainfall more in the day than the night. This is what would be expected if the active discharge from mill chimneys is capable of influencing rainfall.

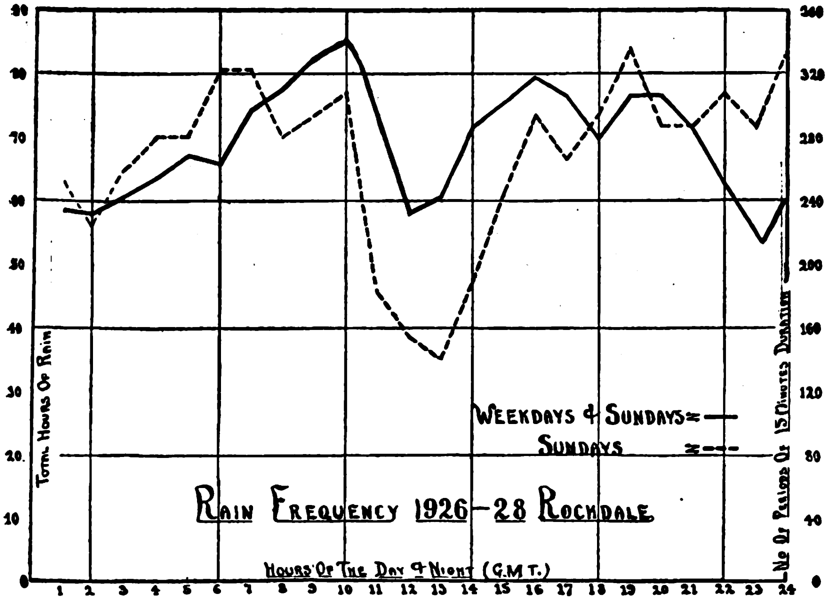

FIG. 2.

The total hours of rain in Rochdale are about four per cent. more on week-days than Sundays.

It is possible to go further and examine the day and night ratios in winter and summer on the supposition that the great difference of temperature of these seasons may have some influence such that the uplift given to the air will be greater in winter than in summer, because in the cold weather of the winter there is a more powerful draught up the chimneys, besides which more coal is then used.

The available data give the following results :—

Ratio of day to night rainfall:—

	Winter	*Summer*
All days	1·15	1·11
Sunday	0·78	0·99
Difference, all days minus Sundays ...	0·37	0·12

Here the ratio for all days is larger in winter than in summer, which means that there are more rainy day hours relative to night hours in winter than in summer, which bears out the supposition made above. The table also brings out that Sundays and all days differ more in winter than in summer.

RATE OF RAINFALL.

Further evidence on the effect upon rainfall of the discharge of smoke and hot gases from mill chimneys is afforded by calculating the rate at which rain falls on the different days of the week. The results in inches per hour are set out in Table IV., and the figures show clearly that Sunday is the day of average lightest rate of rainfall. The rate of fall increases from Sunday to Wednesday and then diminishes to Saturday. This low value on Sunday and the rise and fall on week-days are closely related to a similar low value on Sunday and rise and fall on week-days in the emission of smoke from factory chimneys. By means of an apparatus which was specially devised, and which I have used for two or three years, the particles which are deposited from the atmosphere each hour of the day and night can be counted, and the numbers obtained are found to be a reliable measure of the pollution emitted from factory chimneys and deposited from the air. During the period of eighteen months, covered by the observations on rate of rainfall, the average number of particles which fall on 1·8 square inches per day is shown in the last column of Table IV.

TABLE IV.—RATE OF RAINFALL (INCHES PER HOUR) IN ROCHDALE FROM OCTOBER, 1926, TO JUNE, 1927, AND FROM OCTOBER, 1927, TO JULY, 1928 (OMITTING JUNE) ON EACH DAY OF THE WEEK.

Day of the week.	Rain in inches.	Hours.	Rate of rainfall.	Particles deposited per day on 1.8 sq. in.
Sunday ...	7.77	200¾	0.0387	310
Monday ...	9.35	224	0.0418	459
Tuesday ...	9.62	179½	0.0536	478
Wednesday	11.93	215½	0.0554	499
Thursday ...	10.57	194½	0.0543	451
Friday ...	9.93	210¾	0.0473	462
Saturday ...	14.65	275¼	0.0533	389

The rainfall and the particles deposited are for the period of 24 hours ending at 9 a.m. each day.

These numbers and the corresponding ones for the rate of rainfall are plotted as curves on Fig. 3, and the similarity of one curve to the other is at once evident. The relationship between the two is further brought out by taking the ratio of the average rate of rainfall on Sunday to 1/7th the average of all the days and comparing it with the same ratio for the numbers of particles deposited from the atmosphere. We then get:—

$$\text{Ratio of rate of rainfall} = \frac{0{\cdot}387}{0{\cdot}492} = 0{\cdot}78$$

$$\text{Ratio of pollution} = \frac{310}{435} = 0{\cdot}71$$

The similarity of these ratios, it may be objected, only proves that rain is carrying down particles from the air instead of proving that the discharge of smoke and hot gases is influencing the rate at which rain falls. This objection, however, loses its force when it is remembered that if smoke emission has no influence on rainfall there is no plausible explanation (1) for the higher value of rainfall on week-days than Sundays in the long period of 30 years, (2) for the relatively large number of hours of rain during the working hours of week-days, and (3) for the high rate of fall of rain on week-days compared with Sundays. Further, any strongly marked difference in the rainfall of Sundays and week-days almost necessarily implies that human agencies are at work (unless there is a natural 7-day period with its minimum on Sunday), and if human agencies are invoked the most probable is the issue of smoke and hot gases in large quantities from mill chimneys.

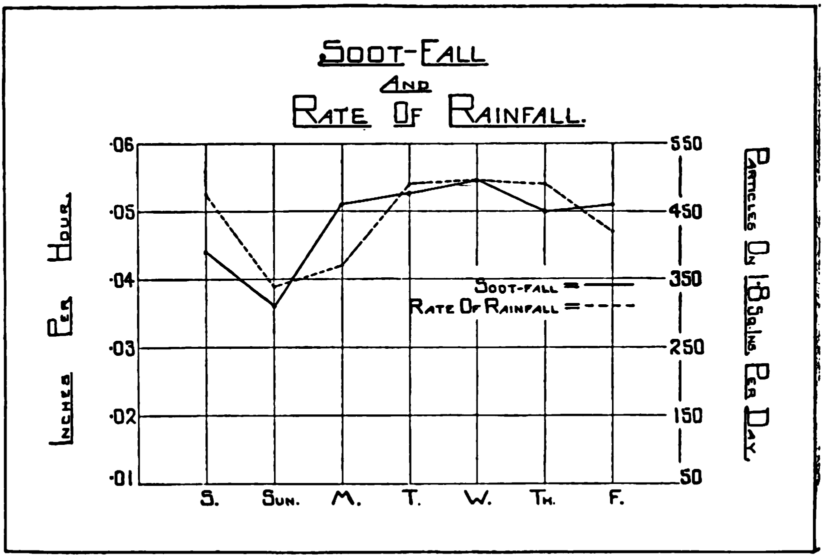

FIG. 3.

Thus it may be reasonably concluded that the variation in the rate of fall of rain is dependent on the emission of smoke from chimneys.

If it be admitted that this emission of smoke and hot gases from factory chimneys can influence rainfall, then it may be asked—how far does this influence extend? Or is it narrowly confined to the immediate vicinity of factories? The question could be answered if the rainfall on the several days of the week were determined in one or more manufacturing towns emitting large quantities of smoke and at the same time in a few adjacent areas which are not dominated by mill chimneys. Again, it may be asked if the small increase in the rainfall of Rochdale in the last 30 years has been in part due to the increase in the number of factories, and if the application of electric power derived from a distance, displacing as it has done many boiler fires and mill chimneys, will be followed in the next decade by a small reduction in rainfall compared with recent records.

DISCUSSION.

Sir Napier Shaw remarked that in any one of the examples the partial exemption of Sunday from rainfall was not very marked, but the concurrence of different methods of approaching the subject enhanced the probability of the conclusion. He would account for increased rainfall in the special circumstances, as the result of deposit upon nuclei of sulphur dioxide or other hygroscopic substances that formed drops below saturation, combined, of course, with the additional loading of the atmosphere by the water vapour of combustion and consequent larger drops on saturation. There was a distinct relation between rainfall and soluble impurities, but not between rainfall and insoluble deposit.

Mr. L. C. W. Bonacina thought that Sir Napier Shaw had really touched the crux of the matter in his reference to the chemical side. It was already pretty well established that the unsaturated condensation helped to cause the bad visibility in winter in industrial districts, and it seemed but a step towards production of light rain in favourable conditions. When travelling through the Durham coalfields he (Mr. Bonacina) had often noticed the tendency to drizzle beneath the leaden smoke-pall. As regards unsaturated fog, anyone who wandered about London in a real fog would find localized patches where dense rolling masses of mist would reduce visibility to a few yards and make everything damp. These localized patches of saturated fog were generally embedded, as it were, in much larger areas of dry, unsaturated fog, with visibility increased to about 50 yards. Mr. Bonacina had always regarded the damp rolling character of the fog as the visible index of saturation. Unfortunately one could hardly wander about town with a dry and wet bulb apparatus.

Dr. C. E. P. Brooks said that the paper reminded him of experiences in Lisson Grove, Marylebone. There were four large smoke stacks, and when the wind was in the right direction the smoke used to blow across the road. If the air was nearly saturated, a fine drizzle used to fall from this smoke, sufficient to keep a wet streak across the road, and he thought that in the course of the year the total precipitation from this cause must have been appreciable. He found Dr. Ashworth's result that the average amount of rain in a " rain-hour " was least on Sundays rather puzzling. He would have expected that if the smoke had any effect it would have caused periods *of slight rain at times when otherwise there would have been no rain.* It did not seem possible for smoke to cause heavy rain, and he would therefore have expected the average rainfall in a " rain-hour " to be decreased slightly by the smoke. This suggested that the alternative explanation, namely, that the heavy rain brought down the atmospheric pollution, was correct.

Mr. L. H. G. **Dines** (*mainly communicated*): It does not seem certain that there is any great significance in the results at which the author has arrived. The question is, how much of it is simply due to errors of sampling? In the first part of Table I. we see that the excess of rain above the mean on Monday was much greater than the deficit on Sunday, and even in the second part there is still a large excess on Monday. Now we must account for the one as much as the other, and errors of sampling seem the simplest explanation. Table III. seems more significant, though it is not based on a very long period. Another point is that on Saturday most factories work only half the day, and this is very clearly shown in Table IV. in the number of particles deposited, but none of the tables show any deficiency of rain on Saturday. In fact, Table IV. is very much the reverse.

Mr. N. **Lang-Smith**: During the discussion the question arose as to whether during any precipitation, soot or particles emitted from chimneys would naturally be brought down with the rain. I made the following remarks:—" On taking my rainfall measurements in the morning I had often noticed a certain amount of soot deposit at the bottom of the measuring glass, the water also being very discoloured. This was particularly noticeable after a fall of rain during foggy atmospheric conditions in winter."

In adding to this it might be of interest to mention that the deposit of soot and discoloration was far more pronounced after a fall of rain with wind from E. or NE. which might be caused by the smoky atmosphere of London drifting over us in a south-west direction.

The President (Sir **Richard Gregory**): Dr. Ashworth has contented himself with bringing together certain facts relating to the distribution of rainfall at Rochdale throughout the days of the week, and has shown that there is a deficiency on Sundays compared with other days. He suggests that this deficiency, or rather excess on week-days in comparison with Sundays, may be due to the emission of hot gases and smoke from factory chimneys. It might be possible to check the result by considering the records on Bank Holidays, when possibly the conditions are the same as on Sundays. Assuming the difference shown in the tables to be real, the actual physical causes of the differences raise some interesting points. I can understand the rain-wizards who pretend to produce rainfall by the emission of a secret smoke from their huts will find much satisfaction from reading Dr. Ashworth's paper. However this may be, the paper presents some results of interest from observations extending over a fair period of years, and as such is an appropriate contribution to this Society.

Dr. J. R. **Ashworth** in reply: Sir Napier Shaw has pointed out how the soluble matter in the air provides one satisfactory reason why atmospheric pollution may augment rainfall, and in this Mr. Bonacina concurs, and I also concur. Sir Napier adds that there is no relation between rainfall and insoluble matter, whereas Mr. Lang-Smith's remarks would imply the contrary. In this connection I may refer to my article in the *Twelfth Report of the Advisory Committee on Atmospheric Pollution*, 1926, p. 77, on the subject of rainfall and insoluble matter. I agree with Dr. Brooks in thinking that the effect of pollution in the air is to cause periods of slight rain at times when otherwise there would have been no rain, but I do not fully appreciate his deduction.

Mr. Dines has raised two important points. First, the high rainfall on Mondays needs explanation as much as the low rainfall on Sundays.

The high rainfall on Mondays is, no doubt, partly fortuitous in the first ten years because in the long period of 30 years it is very much reduced; nevertheless, Monday remains the day of highest rainfall. Now on Monday mornings there is, especially in winter, a vigorous outpouring of dense smoke from the factory chimneys, for the mills after the Sunday rest require re-heating up to the temperature suitable for carrying on their work. Thus the firing of the boilers is heavier on Mondays than on other days of the week and may indirectly have its influence on rainfall. Mr. Dines' second point is that the rate of rainfall on Saturdays remains rather high while the number of particles deposited shows a decided diminution. I think this may be due in part to the lighter and finer particles, which may well be effective in promoting rain, remaining suspended in the air for some time after the mills have closed down for the Saturday afternoon holiday, and such particles would escape being counted at the time. This view finds some support from the fact that when smoothed curves of rate of rainfall and deposition of particles are compared the correspondence between them is as good as could be expected if the rainfall curve is made to lag a little behind the curve of deposited particles. However, I offer these remarks tentatively only, and not as final explanations.

Sir Richard Gregory suggests a comparison of working days with Bank Holidays. The mills, however, do not close on Bank Holidays as a rule, but it might be possible to make use of local holidays for the purpose in question. Unfortunately in Lancashire one manufacturing town almost touches another, and each has its own and a different local holiday time, so that difficulties would arise as to the interpretation of any results which might be obtained.

Meteorological Papers Published by the Royal Society.

The following papers have been issued during the present year to those Fellows of the Society who are participating in the arrangement for the receipt of copies of the meteorological papers published in the *Proceedings* (Sec. A.) of the Royal Society:—

(54) On the theory of the solar diurnal variation of the earth's magnetism.—By S. CHAPMAN.

(55) Measurements of the amount of ozone in the earth's atmosphere and its relation to other geophysical conditions, Part III.—By G. M. DOBSON, D. N. HARRISON and J. LAWRENCE.

(56) On the variability of the quiet-day diurnal magnetic variation at Eskdalemuir and Greenwich.—By S. CHAPMAN and J. M. STAGG.

(57) The transfer of heat by radiation and turbulence in the lower atmosphere.—By D. BRUNT.

(58) A photoelectric method of measuring the light of the night sky with studies of the course of variation through the night.—By LORD RAYLEIGH.

(59) Observations of the height of the ozone in the upper atmosphere, Part II.—By F. W. P. GÖTZ and G. M. B. DOBSON.

Any Fellow wishing to receive copies of meteorological papers through this arrangement with the Royal Society is asked to communicate with the Assistant Secretary at 49, Cromwell Road, for particulars.

POTENTIAL GRADIENT AND ATMOSPHERIC POLLUTION: THE INFLUENCE OF "SUMMER TIME."

By F. J. W. WHIPPLE, Sc.D.

[Manuscript received March 20—Read June 19, 1929.]

I.—INTRODUCTION.

That electric potential gradient depends on the condition of the local atmosphere is generally recognised. At Kew Observatory the subject has been discussed in various ways. Perhaps the most striking manifestation of the influence of smoke production was in 1921, the year of a great coal strike, when the air was for a long period exceptionally clear and potential gradient was persistently low. Earlier, in 1918, Dr. Chree published[1] a study of the visibility of distant objects, and demonstrated that good visibility went with low potential gradient, poor visibility with high. In 1923 Chree and Watson, utilising the records of the Owens air-filter, brought out[2] the correlation between potential gradient and atmospheric pollution. These authors showed that there was a close parallelism between the daily variation of potential gradient and of the pollution measured by the Owens apparatus. The parallelism persisted even on days when the air was comparatively pure, so that it appeared that, even if all effects of pollution could be eliminated, the oscillation of potential gradient in the course of the day would preserve the same general character, having two minima and two maxima in the twenty-four hours.

Whether the air is clean or dirty at Kew depends to a great extent on meteorological conditions, and especially on the wind direction, so that it is not easy to decide how far changes in potential gradient are primarily due to the meteorological conditions themselves and how far to the varying contamination of the atmosphere. Some light is likely to be thrown on the problem by consideration of any change in the habits of the population. The object of the present note is to trace the effects of the introduction of "summer time." The purpose of "summer time" is to make people get up earlier than they did when their daily routine was governed by "mean time" throughout the year. The whole of the daily routine is accelerated by an hour.

When "summer time" was first introduced, many scientists felt that the innovation was to be deprecated as likely to lead to a discontinuity in meteorological observations. That there might be some advantage in a discontinuity, which would be equivalent to an experiment on a large scale, appears to have been overlooked. However that may be, we have now got observations for several years, during which the habits of the population have been moulded by the "summer time" convention and a comparison with the observations of earlier years is likely to prove of interest.

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[1] *Proc. R. Soc.*, **95** (A), 1918, p. 210.
[2] *Proc. R. Soc.*, **105** (A), 1924, p. 311.

II.—POTENTIAL GRADIENT OBSERVATIONS.

Regular tabulations of potential gradient are available at Kew Observatory from the beginning of 1898. The rule has been to tabulate the gradient for ten days a month; normally ten days free from negative gradient are selected. In addition to the monthly means the means for the seasons are always computed. For this purpose summer connotes the four months, May to August, and each mean value is therefore based on the records for forty days. The results of an examination of the figures[3] representing the diurnal variation of potential gradient in the summer in each year from 1898 to 1928 are exhibited graphically in Fig. 1. The times which are tabulated are those of the two minima and the two maxima. The entries in the figure are summarised[4]

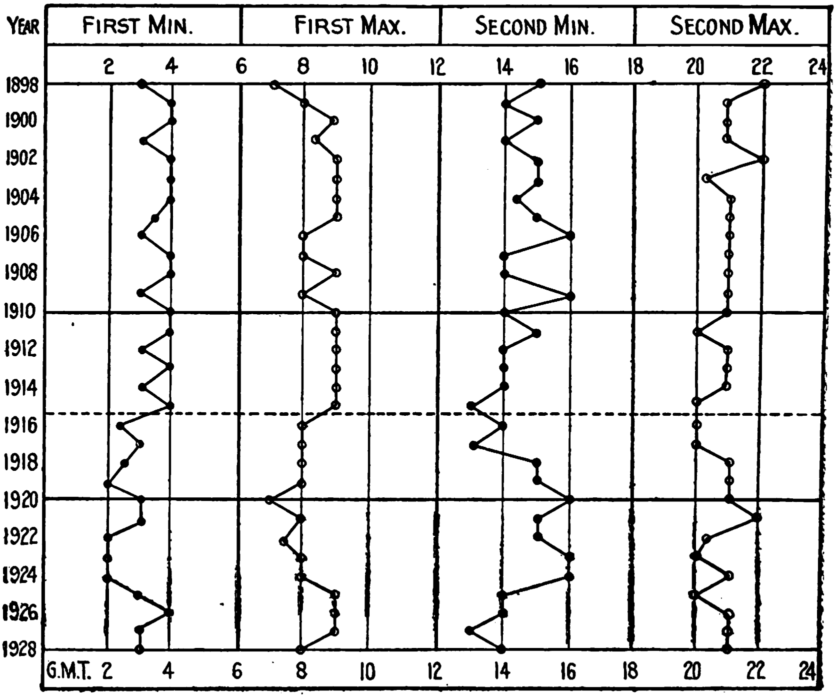

FIG. 1.—Kew Observatory: Diurnal variation of potential gradient in summer. (In the years shown below the broken line summer time was in force.)

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[3] The data for the individual years of the period 1898-1904 have not been published; those for subsequent years are to be found in the following publications: *Reports of the National Physical Laboratory* (Observatory Department), 1905-1909. *Meteorological Office, Geophysical and Meteorological Observations*, 1910. *British Meteorological and Magnetic Yearbook*, Part IV. 2 (Hourly Values, Geophysical), 1911-1921. *The Observatories' Yearbook*, 1922 onwards.

[4] In some cases the potential gradient has equal values in two consecutive hours. The corresponding dot in Fig. 1 is placed between the two hours. In Table I. a half is credited to each hour.

in Table I. As "summer time" was adopted during the war, to economise the national resources, and first came into force in 1916, the years up to 1915 are put in one category in Table I, the years from 1916 onwards in another.

TABLE I.—KEW OBSERVATORY: DIURNAL VARIATION OF POTENTIAL GRADIENT: SUMMER: FREQUENCY OF EXTREMES AT DIFFERENT HOURS.

	First Min.			First Max.			Second Min.				Second Max.		
Hours G.M.T.	2	3	4	7	8	9	13	14	15	16	20	21	22
						Frequency.							
18 years, 1898–1915	0	6½	11½	1	4½	12½	1	8½	6½	2	2½	13½	2
13 years, 1916–1928	5	7	1	1½	8½	3	2	4	4	3	4½	7½	1

It will be seen that, from 1916, there was a clear displacement of the early morning minimum and of the forenoon maximum, each occurring one hour earlier. It is remarkable, however, that the afternoon minimum was displaced in 1918 in the opposite direction, and that for seven consecutive years the minimum was later than it had been in any of the preceding six years. The evening maximum was not affected. Moreover, in 1925 and later years the morning minimum and maximum have reverted to the pre-war hours.

TABLE II.—KEW OBSERVATORY: DIURNAL VARIATION OF POTENTIAL GRADIENT AND OF ATMOSPHERIC POLLUTION. SUMMER MONTHS.

A. Morning Hours.

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
						Potential Gradient (v/m).						
1898–1915	206	188	179	177	190	213	243	265	268	249	221	202
1916–1928	180	169	166	173	187	222	263	278	266	236	212	197
1921–1928	172	161	158	166	182	215	254	271	262	229	203	188
						Atmospheric Pollution (mg/m³).						
1921–1928	.13	.13	.14	.15	.17	.21	.24	.23	.21	.19	.16	.14

B. Afternoon Hours.

G.M.T.	13	14	15	16	17	18	19	20	21	22	23	24
						Potential Gradient (v/m).						
1898–1915	190	181	183	189	202	227	255	276	284	273	250	223
1916–1928	184	180	181	184	192	211	224	239	241	233	211	192
1921–1928	173	168	170	173	182	199	213	231	234	230	207	185
						Atmospheric Pollution (mg/m³).						
1921–1928	.13	.13	.12	.12	.13	.14	.15	.17	.17	.16	.15	.13

Another method of comparing the variations of potential gradient before and after the introduction of "summer time" is to take the mean values[5] for the years 1898-1915 and 1916-28. These are set out in Table II. and graphed in Fig. 2. As may be seen in the graphs, the morning minimum and maximum are accelerated in the second period. The afternoon minimum is unaffected. The evening maximum occurs at about the same time in the two periods, but is much lower in the second.

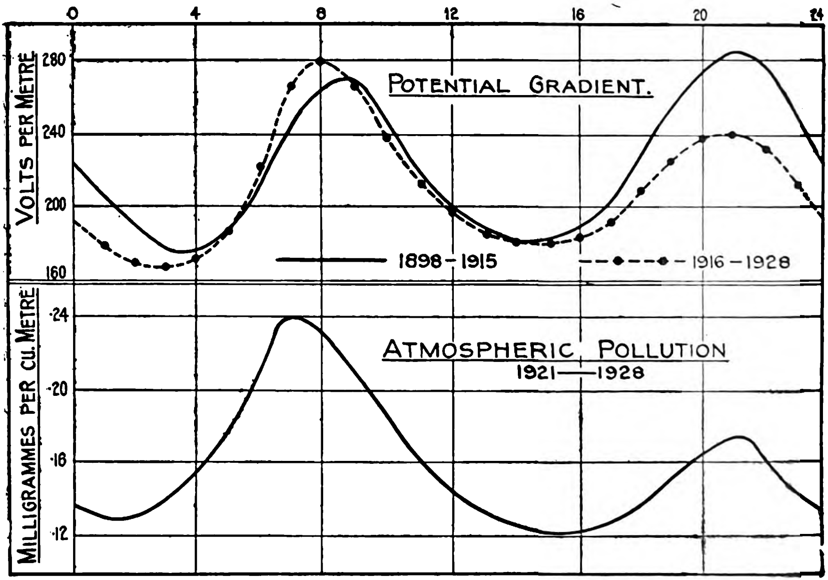

FIG. 2.—Kew Observatory: Diurnal variation of potential gradient and of atmospheric pollution in summer.

III.—THE RECORDS OF ATMOSPHERIC POLLUTION.

Since 1921 one of the automatic filters designed by Dr. J. S. Owens has been in use at the Observatory. In this instrument air is aspirated through filter-paper. The amount of impurity is estimated by comparing the mark left on the paper with a standard scale of shades. Normally[6] the amount of dirt in the air is reckoned as the product of a shade number and the constant .32 milligrammes per cubic metre. In summer the shade numbers determined at Kew are nearly all either 0 or 1. Thus, in reading the lines in Table II, in which the mean pollution for each hour for the summer months of the period 1921-28 is given, it must be remembered that such an entry as .13 means that observations of shade 0 and shade 1 occurred at the named hour approximately in the proportion 19 to 13.

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[5] The readings of the electrographs at Kew Observatory are standardised by frequent observations on the lawn. The system adopted in earlier years was such that the values found for the potential gradient were too low. The values published for the years preceding 1910 have accordingly been multiplied by the factor 1.91. *Vide* Chree, *Phil. Trans. R. Soc.*, A. 215 (1915) 140.

[6] In 1921 and again in 1928 methods were adopted by which greater sensitivity was obtained.

The daily variation of pollution is graphed in Fig. 2. For comparison with the pollution data the mean potential gradient for the period 1921-28 is entered in Table II, but the corresponding graph has not been drawn, as it would be almost indistinguishable from that for the period 1916-28.

The likeness between the curves for potential gradient and for pollution is striking; the principal difference is that the morning minimum and maximum of pollution occur an hour earlier than the corresponding extreme values of the potential gradient. It is a pity that we have no record of the pollution for the years before 1916 to compare with the older records of potential gradient.

IV.—The Causes of the Diurnal Variation in Pollution.

The amount of pollution in the atmosphere depends on various factors. We may assume that all the pollution revealed by the air-filter is due to smoke, but we cannot discriminate between the smoke produced within a mile of the Observatory, in Richmond, Isleworth or Brentford, the smoke from London, and that which comes great distances, from the Midlands or even from the Continent. Investigations of the Atmospheric Pollution Committee show, however, that a large proportion of the smoke produced in any centre falls within a few miles.

As was pointed out to me some years ago by Dr. G. C. Simpson, if the effects of the variation of smoke production and of atmospheric stability are illustrated diagrammatically the reason for a double oscillation of pollution in the course of the 24 hours becomes clear. In a great city some smoke is being produced at all times of day. After the minimum in the early hours of the morning fresh production begins when the first fires are lit. There are few people who have to be out before 5 a.m., and we can hardly suppose that there is appreciable firing before that hour, say 4h. G.M.T. It will be noted that this is much later than the turning point on our pollution curve. By 9 a.m. (8h. G.M.T.) all work is in full swing, and smoke production, whether in the home or in factories, is probably as vigorous at that hour as at any time of day. Fluctuations in the course of the day are likely to be averaged out. The decrease in the evening will begin about 5 p.m. (16h. G.M.T.) and from soon after midnight smoke production is at the minimum. This type of variation is shown in Curve AA of Fig. 3, the hours referring to Greenwich mean time.

The amount of smoke pollution in the air at any time must depend, not only on the rate at which smoke is being produced and dispersed, but also on the rate at which the fine particles settle down to the ground. If all smoke production ceased simultaneously, a considerable time would elapse before the air was purified. To allow for this effect I have made the smoke-production curve fall gently from midnight to 4h.

The extent to which the smoke produced at any time is dispersed through the atmosphere vertically and horizontally depends on the turbulence and velocity of the wind. In the months in question temperature is at its maximum about 15h. and convection will be most vigorous then. The surface wind is strongest about 13h. Accordingly the scattering of pollution should be most thorough about 14h. From this hour onwards up to sunrise the lower atmosphere is becoming more stable, and the stability may be increasing quite rapidly in the last part of this period, when, on many occasions, mist and dew are forming. The daily variation is shown qualitatively in Fig. 3 (Curve BB).

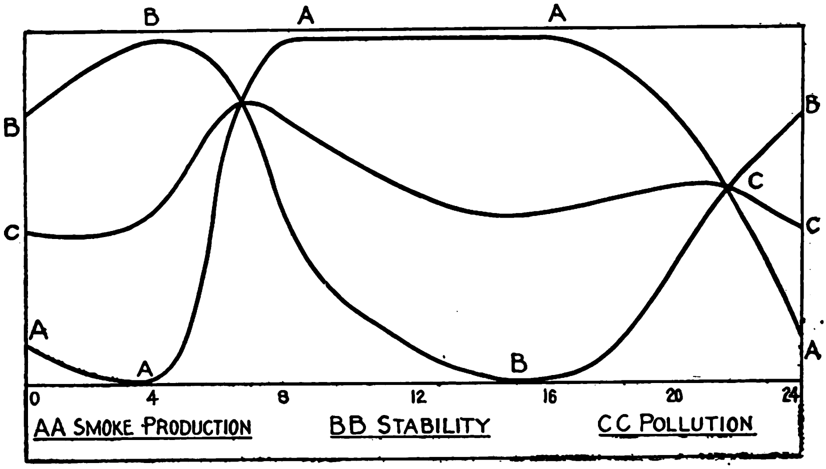

FIG. 3.—Hypothetical diurnal variation of smoke production, atmospheric stability and atmospheric pollution.

In an atmosphere in which smoke production and stability vary in the ways represented by the curves AA and BB respectively, the amount of pollution may be expected to pass through changes such as are represented by the curve CC of Fig. 3. This curve is fairly consistent with the observations.

The pollution maxima and minima are thus explained:—

(*a*) In the early morning, after most fires have gone out, the air is becoming cleaner owing to the gradual deposition and distribution of the smoke particles. At the same time the increasing stability of the air is tending to keep near the ground such pollution as is being produced. When the latter effect is becoming the more important a minimum occurs. In summer the minimum falls at 1h. or 2h. It appears from Chree and Watson's work that the morning minimum in winter is at 5h. At that time of year the settling down process is apparently going on through the night, and the rise corresponds with the lighting of fires in the morning.

(*b*) From sunrise the production of smoke increases, but eventually, as the air becomes more unstable, the smoke is dispersed. The two conditions determine the morning maximum.

(*c*) The afternoon minimum of pollution coincides with the minimum of stability.

(*d*) The evening maximum occurs when decreasing smoke production is becoming of more importance than increasing stability.

V.—The Diurnal Variation of Potential Gradient.

Considering how many influences there are which must affect potential gradient, it is remarkable that the type of diurnal variation resembles so closely that exhibited by atmospheric pollution. In the type of variation prevailing over the oceans and in elevated situations, such as the top of the Eiffel Tower, the minimum occurs at about 4h. G.M.T.; there is a gradual rise to a flat maximum and a steady fall after 19h. The Kew records do not justify us in saying that there are any obvious effects due to such causes as promote this world-wide oscillation of potential gradient. The changes of potential gradient in the course of the day might well be due to the changes in the amount of pollution, the lag of an hour or so in the morning being attributed to the fact that it is not the dust particles which affect potential gradient but other types of pollution, such as hygroscopic nuclei, likely to last longer in the atmosphere. The dependence of potential gradient on pollution of one sort or another is borne out by the behaviour of the morning extremes on the introduction of summer time. It must be admitted, however, that the change in the amplitude of the evening wave in the potential gradient curve is equally striking. As the latter phenomenon cannot be attributed to any influence of summer time, there must be some doubt as to the validity of the explanation of the other one.

Although we have not a complete theory of atmospheric electricity, we can say with some confidence that potential gradient depends partly on world-wide causes, partly on local ones. Amongst these local ones the conductivity of the air takes the first place. Conductivity is itself dependent on the character of the ionization of the air. The rate at which ions are being formed depends *inter alia* on the quantity of radio-active matter floating in the air, and this quantity must depend on the strength and turbulence of the wind. The small ions produced by radio-activity are the principal factor in the conductivity of the air, but these ions are short-lived; they are immobilised when they collide with particles such as Aitken's hygroscopic nuclei.

When this paper was prepared I wrote:—"It is mostly by adding to the number of these nuclei that the pollution of the air affects its conductivity."

Recent work by Mr. H. L. Wright indicates, however, that the electrical resistance of the air is correlated more closely with the number of coarse particles than with the number of condensation nuclei. Apparently the coarse particles, though far less numerous, are more effective than the nuclei in eliminating the small ions.

With so many factors to be considered and with but little information as to their fluctuations, it is not surprising that the diurnal variation of potential gradient is but half understood.

I hope that before long there will be at Kew continuous records of such variables as the conductivity and ionization of the air. With these records we shall have a better chance of understanding the phenomena which have been pointed out but not completely explained in the present note.

APPENDIX.

(Added July 25, 1929.)

POTENTIAL GRADIENT AND POLLUTION IN WINTER AND IN THE EQUINOCTIAL MONTHS.

It may well be asked whether the change in type in the diurnal variation of potential gradient in recent years is confined to the summer. I have therefore set out the averages for the equinoctial months and for the winter in Tables III. and IV. and Figures 4 and 5, which are comparable with Table II. and Fig. 2.

It will be seen that in these seasons there is close agreement between the variation curves for the earlier and later periods.

To the small apparent increase in potential in the later period no importance should be attached, as there is some doubt as to the validity of the factor by which the gradients for the earlier years were multiplied to allow for the change in the method of standardisation. The relations between the successive maxima and minima have been maintained.

Further, the potential gradient and atmospheric pollution march together. It was noticed that in summer pollution was less in the

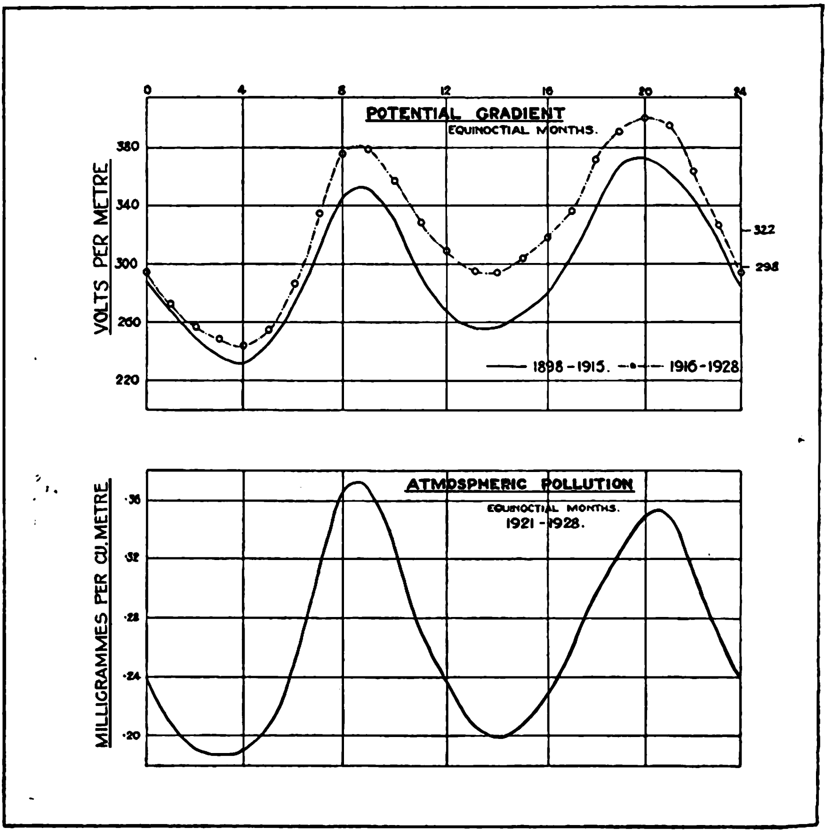

FIG. 4.—Kew Observatory: Diurnal variation of potential gradient and of atmospheric pollution in the equinoctial months

TABLE III.—KEW OBSERVATORY. DIURNAL VARIATION OF POTENTIAL GRADIENT AND OF ATMOSPHERIC POLLUTION. EQUINOCTIAL MONTHS.

A.—MORNING HOURS.

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
Potential Gradient (v/m).												
1898-1915	267	249	237	234	245	271	309	345	351	331	291	269
1916-1928	272	257	248	243	255	285	334	377	379	357	327	309
1921-1928	256	240	230	224	236	261	307	351	357	341	314	299
Atmospheric Pollution (mg/m³).												
1921-1928	.21	.19	.19	.19	.21	.25	.31	.37	.37	.33	.27	.24

B.—AFTERNOON HOURS.

G.M.T.	13	14	15	16	17	18	19	20	21	22	23	24
Potential Gradient (v/m).												
1898-1915	257	257	266	278	304	339	366	371	362	344	317	286
1916-1928	296	295	304	319	337	372	393	400	394	362	324	294
1921-1928	286	284	296	305	331	362	381	383	377	345	312	282
Atmospheric Pollution (mg/m³).												
1921-1928	.21	.20	.21	.23	.26	.30	.32	.35	.35	.31	.27	.24

TABLE IV.—KEW OBSERVATORY. DIURNAL VARIATION OF POTENTIAL GRADIENT AND OF ATMOSPHERIC POLLUTION. WINTER MONTHS.

A.—MORNING HOURS.

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
Potential Gradient (v/m).												
1898-1915	361	340	325	319	326	345	387	434	465	471	448	426
1916-1928	373	347	335	330	333	351	394	455	488	492	478	466
1921-1928	356	330	318	316	319	338	380	437	472	474	463	454
Atmospheric Pollution (mg/m³).												
1921-1928	.24	.21	.20	.19	.19	.21	.27	.39	.49	.49	.45	.40

B.—AFTERNOON HOURS.

G.M.T.	13	14	15	16	17	18	19	20	21	22	23	24
Potential Gradient (v/m).												
1898-1915	408	401	412	429	452	469	478	474	465	448	421	387
1916-1928	445	427	435	458	481	506	511	501	484	463	430	397
1921-1928	433	407	422	440	460	480	489	479	462	440	406	376
Atmospheric Pollution (mg/m³).												
1921-1928	.37	.35	.37	.40	.44	.47	.48	.47	.46	.41	.35	.27

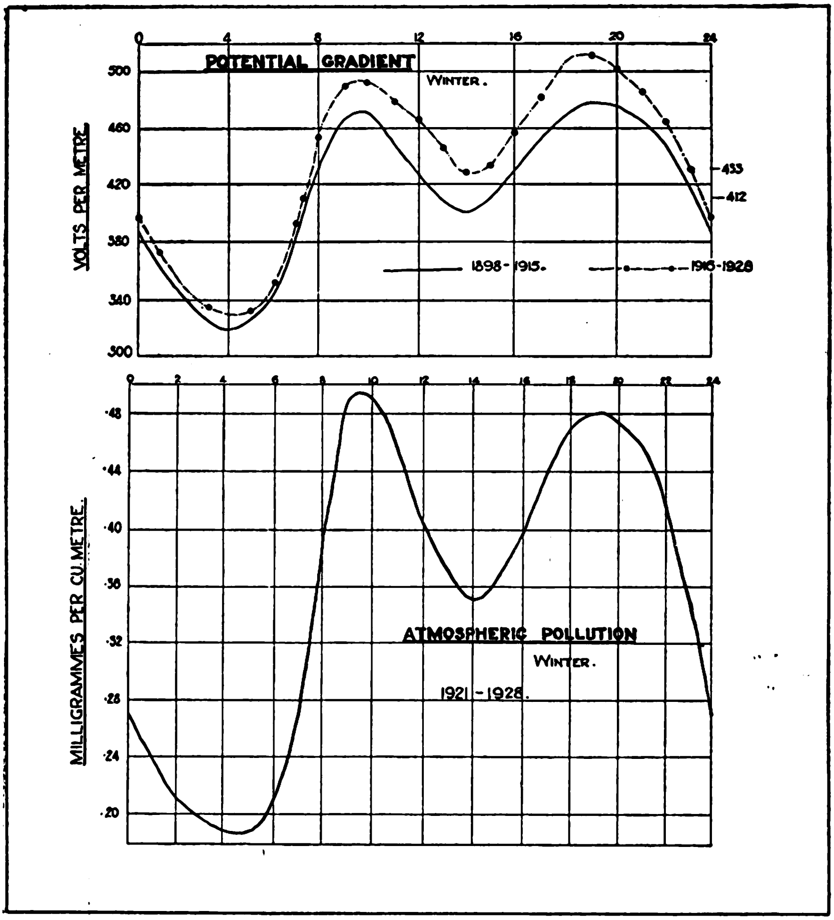

FIG. 5.—Kew Observatory: Diurnal variation of potential gradient and of atmospheric pollution in winter.

evening than in the morning. In the winter there is little to choose between morning and evening. In winter our pollution is due to a great extent to domestic fires. These fires are kept up until late in the evening, whereas the pollution in summer may be attributed almost entirely to industrial processes which are in action only in the daytime.

This distinction between summer and winter habits is a comparatively recent growth. If we may trust to the evidence of the potential gradient curves it is clear that as long as cooking was done by coal fires the pollution was as great in the summer evenings as in the mornings. Nowadays when most cooking is done by gas there are few fires active in the evening and the air keeps comparatively clean.

I am indebted to Mr. E. Boxall for computing most of the tables in this paper. Mr. Boxall has been responsible for the care of the electrograph and for the tabulation of the curves during the greater part of the period under review.

DISCUSSION.

Dr. G. C. SIMPSON said that some years ago it was the custom to consider that the two maxima of atmospheric pollution shown in Fig. 2 were due to the cooking of the morning and evening meals. As this explanation did not seem satisfactory he was led to the explanation of the daily variation of atmospheric pollution given by Dr. Whipple. It is important to notice that in Fig. 3 the curve of stability, BB., is determined by Greenwich time, while the curve of smoke production, AA, depends on clock time. The combination of the two curves will therefore shift with summer time, and the two maxima of pollution will occur earlier in the summer than in the winter, if no other factors come into play. It has not, however, been possible to demonstrate this shift from the records of atmospheric pollution alone, but Dr. Whipple has now shown that the shift comes out clearly in the morning oscillation of the potential gradient. If the work of Chree and Watson left any doubt about the direct effect of atmospheric pollution on potential gradient, Dr. Whipple's paper will entirely remove it. There is, however, one difficulty. Chree showed that the same type of daily variation of potential gradient exists at Kew even when there is no pollution as measured by the Owens filter. This, however, could be explained by the presence of Aitken nuclei, which act like the dust particles and are always present, even when there is no dust. Over the land the daily variation of these nuclei will also be determined largely by the stability of the atmosphere, and therefore the character of the variation of the potential gradient will not change when the dust disappears. Over the sea, on the other hand, there is nothing to give the Aitken nuclei a marked daily variation, therefore over the sea the potential gradient will not be affected by them. The daily variation of the potential gradient will then be determined by some other factor, and this appears to be a variation of potential gradient which is the same all over the world at the same time, as demonstrated by Mauchly, the origin of which is probably cosmical, although Dr. Whipple and others think it may be due to the activity of thunderstorms. In any case we seem to be getting nearer to a physical explanation of the difference between the daily variation of potential gradient over the land and over the sea. In the former, the variation of the potential gradient is largely, if not entirely, governed by the variation of dust and nuclei, while over the sea it is governed by a world-wide effect, the origin of which is not yet known.

Dr. WHIPPLE wrote in reply: I am glad to have this opportunity to thank Dr. Simpson for allowing me to publish his explanation of the occurrence of two maxima of pollution in the 24 hours. The questions whether the variations in the conductivity of the air depend mostly on the changes in the number of nuclei and whether the gross dust particles have a direct effect can only be answered by an appeal to experiment. There are at present few observations which throw light on these questions. As to the world-wide type of diurnal variation of potential gradient I do not think the cause can be regarded as cosmical. The variation is governed by solar time, not by sidereal time. In some way or other the sun is influencing the earth, and this influence is more or less powerful according to the face which the earth is presenting to the sun. Whether the intermediate cause is the production of thunderstorms is an open question, but the arguments in favour of that view are very strong.

A Note on Fogs in the region of the Channel Islands.

The aims of this investigation were two in number:—

(a) To discover whether differences in air and sea temperatures in the neighbouring parts of the English Channel in the immediate past before a fog formed at Guernsey, were more or less invariable heralds of that fog; and

(b) To discover whether, in the absence of an affirmative answer to (a), any consideration of the more remote history of the air concerned in the fog formation would help towards the forecasting of the fog.

The investigation concerned itself with the period extending from the 1st of April, 1928, to the 31st of March, 1929, and consisted of two parts. First, when a fog occurred at Guernsey the sea and air temperatures within the previous 7 hours were compared, the readings of sea and air temperatures used being those recorded by cross-Channel steamers operating in the region of the Channel Islands, and published in the *Daily Weather Report* of the Meteorological Office, London; secondly, a careful examination was made of the synoptic charts for the two or three days preceding those same fogs.

In all 26 fogs were available for examination. Of these 5 were definitely regarded as "radiation" fogs and hence were excluded from further consideration in the present connection, and one was of very doubtful origin and hence was also excluded. Taking "winter" as the months October to March (both inclusive) and "summer" as the months April to September (both inclusive), the results of the first part of the inquiry with regard to the remaining 20 cases were as follows:—

Within 7 hours before fog.	Winter.	Summer.
Air temperature > sea temperature	3	5
Air temperature = sea temperature	3	1
Air temperature < sea temperature	8	0

The table suggests that, at least in winter, it is far from necessary for fog formation that the air temperature within the few hours preceding the fog should be above the sea temperature. As it is generally believed that this should be the case this result seems not devoid of value, and the number of cases in which the air temperature was actually lower than the sea is noteworthy. In summer the general belief seems worthy of greater credence.

The second part of the inquiry, that into the more remote travel of the air, gave results of far greater consistency, for of the 20 cases no less than 19 had histories in which the air concerned had travelled during the preceding two or three days over long tracks from the south, and it was noted that in all these cases the temperatures in the area traversed had been relatively high.

It would appear, therefore, that the forecaster concerned with forecasting the occurrence of fog in the Channel Isles is likely to derive most help from a consideration of the track of the air during the preceding two or three days and that if that air has been warmed considerably in its travel fog becomes within possibility. On the other hand the fact that in the immediate past the air temperature in the neighbourhood of the Channel Isles has been greater than the sea temperature does not seem likely to be of any real assistance to him.

W. H. Pick.

6th August, 1929.

A. G. Forsdyke.

VERTICAL AIR CURRENTS AS MEASURED BY PILOT BALLOONS.

By A. J. BAMFORD, M.C., M.A., B.Sc.

(Superintendent Colombo Observatory, Ceylon).

[Manuscript received April 3—Read June 19, 1929.]

Measurements of the vertical velocities of pilot balloons have been included as part of the routine work of Colombo Observatory during the past seven years. The method adopted has been to take the theoretical rate of rise of each balloon as derived from its free lift and weight, by using the ordinary Dines formula,[1] and to express the actual vertical velocity derived by the tail method, as an offset from this quantity in metres per minute.

The tail method has been in regular use at Colombo since 1921, and I have been rather interested to note the way in which it seems to have advanced in favour with meteorologists elsewhere since the last time that I had the privilege of reading a paper before this Society dealing with upper-air work.

I am quite aware that if a couple of balloons are released within a few minutes of each other from the same spot they may ascend at very different rates, but nevertheless I submit that with the amount of information now available at Colombo, which comprises several thousand flights, it is legitimate to make a few generalisations.

It may be explained here that the flights in question were all made with rubber balloons of the type supplied through the London Meteorological Office, filled with hydrogen generated on the spot from caustic soda and aluminium scraps. The normal procedure is to use a tail 20 metres long, the flag at the end consisting of a foolscap-size carbon paper that is of no further use in a typewriter. A very thin bamboo slat is used to keep the tail spread out. White tails are used on occasion, when the background warrants their use. Five metres from the centre of the balloon a small circular patch of paper is attached without any bamboo stiffening, and serves to give the altitudes during the first few minutes, while the angle subtended by the twenty-metre tail is too big to be used conveniently.

All tail lengths are checked immediately before release by means of pegs inserted in the ground for the purpose. At the very beginning, before even the 5-metre tail shows in the field of view along with the balloon, measurements of the balloon's diameter are made—the assumption being that the diameter does not change much in the first minute and a half. However, this last item does not enter much into the discussion in this paper, since the lowest altitude discussed is half a kilometre, by which height the short tail is usually in use.

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[1] This point has been discussed in more detail in *Bulletin*, *Colombo Observatory*, No. 5, p. 21. It may be mentioned here that the value of q used in the formula $V=qL^{\frac{1}{2}}/(L+W)^{\frac{1}{3}}$ throughout this paper is 81.

The computation is greatly facilitated by the use of various devices due to Mr. Harold Jameson, details of which have been published in the *Bulletins of the Colombo Observatory*, both before and after their incorporation as a section of the *Ceylon Journal of Science*.[2]

Tables of monthly averages are given in this paper, in which velocities are shown as offsets, in metres per minute, from the theoretical rate, while the more important figures in them are also shown in graphical form. It is, of course, realised that small errors may be introduced, owing to the grids in the theodolites not being perfect, but such troubles would produce hardly any change in the shape of the curves—they might shift the zero line up or down and alter the scale slightly, but with continuous use of the same theodolites they would produce but little effect on the relative results.

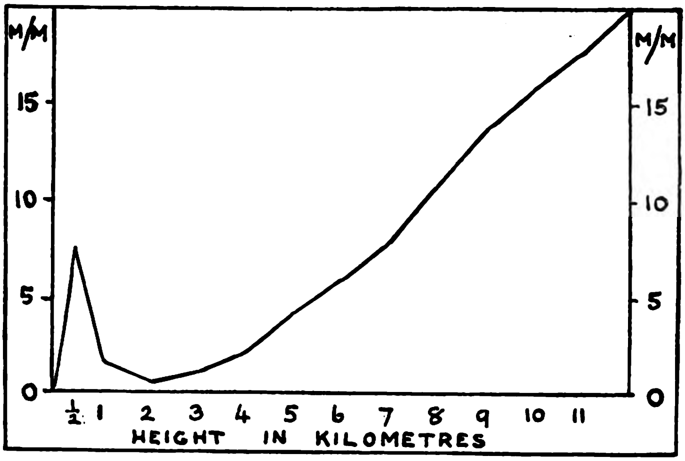

FIG. 1.—Average offsets of vertical velocity from all flights.

(In this and subsequent figures M/M signifies metres per minute.)

Fig. 1 gives a summarised view of all flights and shows the average variations in velocity over successive steps of from 0 to ½, 0 to 1, 0 to 2 . . . . kilometres. On the left, the offset for the lowest half kilometre is the mean of 3,511 observations, and the numbers fall off towards the right as the balloons are lost sight of in cloud or otherwise. It will be seen that all average velocities correspond to a faster rate of rise than the theoretical value. The shape of the curve is, however, striking, rapid ascent in the first half kilometre being followed by an almost equally sudden collapse towards the normal rate of ascent, before the commencement of a steady acceleration from three kilometres upwards.

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[2] *Bulletins of the Colombo Observatory*, No. 5. Upper air observations. Appendices by H. Jameson.
Ceylon Journal of Science (Sect. E), **1**, Pt. 1. Notes on computing devices, by H. Jameson.

Familiarity with the phrase "tropical convection" makes one expect the observational curve to be above, rather than below the theoretical curve, but an explanation is required of its particular shape, and especially of the sharp drop from half a kilometre to one kilometre. The first explanation that will probably suggest itself is that the point on the curve which corresponds to the range from the surface to half a kilometre may have been raised by a number of very rapid, short flights, in which the balloon was lost sight of below a kilometre. This suggestion does not bear scrutiny, however. In Table II average velocities up to half a kilometre are given for balloons that reached a height of at least one kilometre, and on the whole are more rapid than the averages from all flights used in Fig. 1. The fact that flights made beneath very low cloud are of less than average vertical velocity is itself interesting, but at the moment we are only concerned with its bearing on the interpretation of the curve in Fig. 1.

The convectional effect of the general heating of the tropics suggests a general ascent, and may account for much of the steady increase from 2 kilometres upwards, but it is much too wide a process for its average effects to be other than smooth, or to explain the sharp change in average velocity above and below half a kilometre. Much of the very rapid ascent in the lowest half kilometre must be attributed to the local diurnal heating up of the surface in the immediate neighbourhood, as opposed to the general heating of the tropics as a whole. If this gave a simple uniform rise, or whirls of dimensions of a few metres only, up to half a kilometre, and then merely eased off until the wider movement took charge, we might expect the offset of the velocity from the surface to one kilometre to be of the order of half the offset of the velocity from the surface to half a kilometre, but not so far below it as the curve shows.

Fig. 1 demands that the average vertical velocity in the layer from half a kilometre to one kilometre must be decidedly less than the theoretical rate of ascent, and in subsequent curves it will be seen that each month shows the same thing when considered separately.

Thus at first sight the balloon figures suggest that the air is moving upwards in the section from the surface to half a kilometre and moving downwards in the section from half a kilometre to one kilometre, which would result in a curious congestion of air somewhere near the half kilometre.

In the absence of a set of barometer readings at this height we cannot say that such a congestion does not exist, though we may fairly be sceptical about it. If it does exist the extra air would certainly try to escape horizontally, and the horizontal velocities at half a kilometre do not show any particular evidence of such an escape, as they are roughly intermediate between those at the surface and one kilometre.[3]

It may be argued that the horizontal velocities which are discussed in terms of metres per second are so much greater than the vertical velocities, that are usually given in metres per minute, that variations in the latter might be adjusted by such small variations in the former that they might exist and yet not be very apparent. This would only be the case if the upward and downward velocities indicated occurred only over a small area close to the Observatory. If there is a layer in the neighbourhood of half a kilometre which is receiving extra air from above and below, and if this layer is of considerable horizontal area, and the whole resulting congestion of air in it has to escape horizontally, the resulting horizontal velocity would have to be far greater than the vertical ones that produced it, in the same way that a sea breeze may have a much greater horizontal velocity than any of the convection columns that may be regarded as its motive power.

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[3] Average values of horizontal movements are published in the *Ceylon Journal of Science* (Sect. E), **1**, Pt. 3.

The even flatness of the land round the Observatory is an argument against conditions above it, being very different from those a few miles away, but on the other hand the fact that the Observatory is near the coast makes it possible that the vertical velocities over it may be only typical of a narrow strip near that coast. However, the phenomenon shows in each of several different months, and we should expect any such coastal effect to vary considerably from one month to another, as the general conditions of air circulation over Ceylon varied. It must be remembered, too, that in practice by the time the balloons have risen a kilometre they may be at considerable distances horizontally from their starting points and in varied directions.

Support can be obtained for the idea that we are not dealing with a purely local phenomenon, that is primarily due to Colombo's position near a coast line, by the similarity between the results obtained here and some of those obtained in Palestine in 1918.

The tail method was not used in Palestine, but vertical velocities were measured by the use of two theodolites and by a rangefinder. The chief observing stations used in the summer of 1918 were well inland from the coast, and a similar indication was obtained of accelerated ascent up to 2,000 feet and retarded ascent above this height. The phenomenon was more marked in summer than winter, *i.e.*, at the time of year when conditions in Palestine approximated most to those in Colombo.[4]

So far, then, we must accept the possibility of such a congestion between the upward and downward general movements, because we have no proof that it does not exist and the evidence of the balloons appears to be in favour of its existence.

Before proceeding to outline a more promising explanation of the facts already submitted it will be necessary to call attention to a few connected figures. Table I shows the rather striking fact that the proportion of balloons that show an accelerated rate of rise in the lowest half kilometre is only 53 per cent. of the whole and that for individual months, considered separately, this proportion only varies from 58 to 48 per cent. The average variation of all flights from the theoretical rate of rise, irrespective of sign, is 25.6 metres per minute, and if this average applied throughout, to both accelerated and retarded flights, the 53 per cent. would give a mean rate of acceleration for the whole of 0.06 × 25.6 or less than 2 metres per minute, instead of the observed value of over 7 metres per minute.

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[4] *Q.J.R. Meteor. Soc.*, **46**, 1920, pp. 28-29. Observations of the upper air over Palestine, by A. J. Bamford.

TABLE I.—AVERAGE OFFSETS OF VERTICAL VELOCITY FROM THE SURFACE TO HALF A KILOMETRE FOR ALL FLIGHTS OBSERVED TO THAT HEIGHT, TOGETHER WITH THE NUMBER OF FLIGHTS AND THE PERCENTAGE OF THEM IN WHICH THE VELOCITY WAS ABOVE THE THEORETICAL VALUE.

Month.	Morning.			Afternoon.			All.		
	Velocity.	No.	%	Velocity.	No.	%	Velocity.	No.	%
	m/min.			m/min.			m/min.		
Jan.	5.8	116	49	7.9	85	51	6.7	201	50
Feb.	4.0	129	52	6.5	104	44	5.1	233	48
Mar.	7.2	146	49	12.3	142	53	9.7	288	51
April	4.6	139	51	10.9	110	55	7.4	249	53
May	2.1	173	50	3.7	147	49	2.8	320	49
June	4.6	150	45	9.4	150	58	7.0	300	51
July	9.3	173	59	6.1	166	53	7.7	339	56
Aug.	7.4	171	56	5.3	144	50	6.4	315	54
Sept.	13.9	193	59	6.8	170	50	10.6	363	55
Oct.	7.6	185	58	3.1	160	48	5.5	345	53
Nov.	7.6	165	60	10.0	147	52	8.7	312	56
Dec.	15.8	151	59	8.7	95	57	13.0	246	58
Mean	7.5	1891	54	7.6	1620	52	7.6	3511	53

The signs of all offsets in the above table are positive.

Roughly speaking, we can say that only about half the balloons are accelerated in their ascent in the lowest half kilometre, but the acceleration due to the upward movement of the air, in cases where it occurs, is considerably greater than the corresponding retardation in the almost equal number of cases in which it occurs.

In the layer from half to one kilometre the percentage of accelerated ascents is only 39, and if we take the average theoretical rate of ascent as of the order of 130 metres per minute and use the offsets in Table II of +8.4 and +1.7 we get for the velocity offset in this layer −4.4 metres per minute.

This would be given by an average offset of all flights irrespective of sign of 20 metres per minute, since (.39 − .61) × 20 = 4.4, and without claiming this precise result we can fairly say that the average variations in the accelerated and retarded groups of flight are more nearly equal to each other in this layer than in the lower one, and that their magnitude is appreciably less than that of the accelerated group in the strata nearer the earth.

I submit that most of the above facts are reconciled if we assume that the local convection set up near the surface is largely in the form of rolling whirls of several hundred metres radius. If the balloon is accelerated by being caught up in the upward motion of such a whirl it is liable to continue to be under the influence of that same whirl when that influence becomes downwards, so that the mere fact of some unusually rapid ascents at

TABLE II.—FLIGHTS SEEN TO A KILOMETRE ONLY. AVERAGE OFFSETS OF VERTICAL VELOCITY FROM SURFACE TO HALF A KILOMETRE, AND FROM SURFACE TO ONE KILOMETRE, NUMBER OF FLIGHTS, AND PERCENTAGE OF FLIGHTS IN WHICH THE VELOCITY UP TO A KILOMETRE WAS ABOVE THE THEORETICAL VALUE.

Month.	Morning.				Afternoon.				All.			
	Velocity.		No.	%	Velocity.		No.	%	Velocity.		No.	%
	0-½ km.	0-1 km.		0-1.	0-½ km.	0-1 km.		0-1.	0-½ km.	0-1 km.		0-1.
	m/min.	m/min.			m/min.	m/min.			m/min.	m/min.		
Jan.	+ 6.0	+2.4	101	45	+ 8.3	+2.6	69	47	+ 6.9	+2.5	170	46
Feb.	+ 2.8	−0.5	118	43	+ 5.9	−0.8	90	41	+ 4.2	−0.6	208	42
Mar.	+ 4.9	−1.9	128	38	+11.2	+2.6	121	48	+ 7.9	+0.3	249	43
April	+ 6.0	−1.4	113	41	+12.3	−1.0	92	45	+ 8.8	−1.2	205	43
May	+ 3.8	−1.6	126	46	+ 1.6	−4.6	99	33	+ 2.8	−2.9	225	40
June	+ 7.0	+0.2	94	44	+13.0	+1.9	66	48	+ 9.5	+0.9	160	45
July	+ 9.4	+1.5	102	49	+ 5.8	−0.4	98	52	+ 7.7	+0.6	200	50
Aug.	+12.6	+5.4	76	55	+12.6	+2.5	61	43	+12.6	+4.1	137	49
Sept.	+17.2	+8.7	102	54	+ 9.4	+3.1	82	49	+13.7	+6.2	184	52
Oct.	+10.4	+4.1	134	57	+ 3.2	−1.5	117	41	+ 7.0	+1.4	251	49
Nov.	+ 8.5	+3.7	138	58	+11.2	+4.1	119	48	+ 9.7	+3.9	257	54
Dec.	+12.8	+5.0	126	54	+ 6.3	+6.4	86	51	+10.1	+5.6	212	53
Mean	+8.4	+2.1	1358	49	+8.4	+1.2	1100	46	+8.4	+1.7	2458	47

the start establishes a probability of some unusually slow ascents in the next stage.

The diagram in Fig. 2 shows the essentials of the idea of such a convectional whirl in otherwise still air. The main motive power is in the ascent above A and the existence of the whirl depends primarily on the fact that the convection here is stronger than elsewhere (*e.g.*, over D E).

Arrows are shown to indicate the movement in the outer limit of the whirl. Similar, though weaker, movements may be expected nearer the centre and might have been shown by concentric rings of smaller arrows. The reason for not showing these inner rings is purely to avoid overcrowding the diagram.

In otherwise still air, the horizontal motion above the centre may be loosely described as due to the upper part of the ascending column above A tumbling over sideways into regions of less rapid ascent, or of descent. If there is a little independent horizontal movement it will help to decide on which side the tumbling over takes place, besides adding to the horizontal movement. The diagram has points in common with the ordinary ones often seen in explanation of the sea-breeze effect, the difference being that in that case a definite reason is assigned why the convection should be unequal at the two extremities of the system, and here we are merely starting from the looser basis that convection is not usually perfectly uniform.

As the main motive power is above A we should expect the velocities to be smaller on the right side of the diagram than on the left, owing to friction, so that at any particular horizontal level the sum of the vertical components of movement taken over the whole whirl would be more upwards than downwards. This is a particularly important point, in view of what we shall find later, with regard to the effect of such a whirl on balloons.

Since the main motive power, as indicated by the longer, nearly vertical, arrows on the left, depends on the heating effect of the ground, it seems reasonable not to draw the whirl as a complete circle, but to show the area of maximum ascent near the ground and hence show the part above the centre as more complete than that below. The exact amount of the horizontal velocity component in the part of the whirl just above the ground need not be gone into fully for the moment, as we are more concerned with its type than its amount.

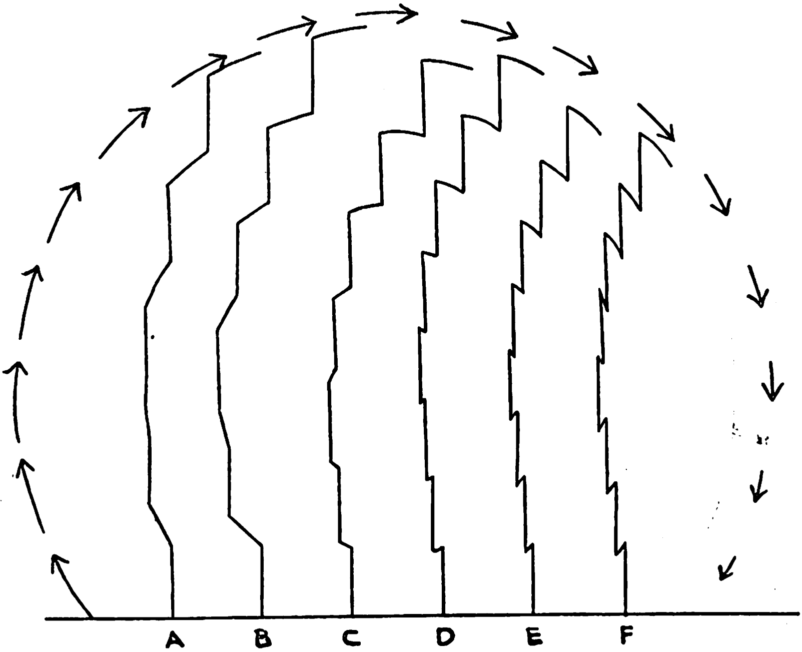

FIG. 2.—Vectors of movements of six balloons released from equidistant points in a convectional whirl.

Let us consider now the action of such a whirl on balloons released at various points on its base. In Fig. 2 the tracks of six balloons are shown starting from points equidistant along the base. In each case two vectors are drawn to denote the movement in each minute. The first one is a vertical ray of uniform length drawn upwards from the point of release and denoting the theoretical rise in still air due to the balloon's buoyancy and weight, the next one is drawn from its summit and is obtained from the movement of the whirl regarded as rotating round the centre as a whole with the angular velocity indicated by the arrows on its rim. The end of this second vector gives a rough idea of the position of the balloon one minute after release due to both causes, and is the starting point of another pair of vectors for the second minute and so on.

As regards scale it will be found that if the theoretical rise is taken as 125 metres per minute the summit of the whirl is about one kilometre above the surface.

The average speed from one to two kilometres is very near the theoretical rate, suggesting that these large whirls due to local convection have to a great extent spent themselves at a height of one kilometre. The offset in Table III is just negative, so that one kilometre is probably an under-estimate rather than an over-estimate of the height.

TABLE III.—AVERAGE OFFSETS OF VELOCITY BETWEEN ONE AND TWO KILOMETRES, NUMBER OF FLIGHTS, AND PERCENTAGE OF FLIGHTS IN WHICH THE VELOCITY WAS ABOVE THE THEORETICAL VALUE.

Month.	Morning.			Afternoon.			All.		
	Velocity offset.	No.	%	Velocity offset.	No.	%	Velocity offset.	No.	%
	m/min.			m/min.			m/min.		
Jan.	−1.6	81	46	−2.0	46	40	−1.7	127	44
Feb.	−3.6	84	36	−7.0	60	33	−5.0	144	35
Mar.	−0.6	85	46	−4.2	77	36	−2.3	162	41
April	−0.7	72	40	+0.5	55	44	−0.2	127	41
May	−2.0	56	38	−6.5	34	22	−3.7	90	32
June	+1.8	20	55	+5.8	8	56	+2.9	28	55
July	+4.9	34	56	+6.8	26	71	+5.8	60	62
Aug.	+0.1	18	61	+12.3	15	80	+5.6	33	70
Sept.	+7.6	33	76	−2.5	24	52	+3.4	57	66
Oct.	+1.9	87	49	−0.9	69	43	+0.7	156	47
Nov.	+1.9	93	49	+1.3	87	53	+1.6	180	51
Dec.	+0.3	93	51	−0.4	51	51	+0.1	144	51
Mean	+0.2	756	47	−1.2	552	45	−0.4	1308	46

Let us now consider the six balloons in detail. It will be seen that in the first few minutes the three on the left (A, B, C) are accelerated upwards by the whirl and the other three (D, E, F) retarded, though in one case in each group (C and D) the variation is not great. With only 6 items the ratio of 3 to 3 is as close as we can expect to attain to the 53 per cent. of acceleration, and the figure makes it quite clear that, as in the experimental results, the acceleration upwards of the three that are helped is greater than the retardation of the three that are retarded.

All are displaced to the left at first, and to the right after they have passed the level of the centre.

In the case of A and B the ascent is still assisted in the upper half, but to a decreasing extent as they reach parts of the whirl where the movement is less upwards, and more across. The balloon that starts at C is particularly interesting. It is assisted at first, but passes too near the centre for this assistance to be very great; after passing the level of the centre it crosses from the left to the right half and so gets into an area of descent.

The balloons D, E and F are all retarded throughout, but to a considerably greater extent in the upper half, partly because the effect of angular velocity is greater as they recede from the centre, but even more because they are displaced by the general system of the whirl to the right of their starting points, and so to parts of it in which the movement is more downwards.

The total displacement experienced by the six balloons in the upper half of the diagram is certainly more downward than upward, while we can even reproduce an approximation to the observed result of 39 per cent. of accelerated flights in the layer from half to one kilometre. It is a moot point whether the effect of the whirl on balloon C in the upper half of the diagram is mainly downward, or about equally upward and downward. If the former is the case we must say that 2 out of 6, or 33 per cent., are accelerated, if the latter is more correct, 2½ out of 6 gives 42 per cent., and either of these percentages come reasonably near to the observed 39.

The tracks of these balloons thus appear to reconcile the observed facts regarding the amount and frequency of the balloon's vertical acceleration or retardation with the expectation of a general ascent of the air throughout the lowest kilometre, which ascent is more marked in the lower half than the upper one—an expectation which, as pointed out on page 369, is not at variance with the whirl system.

The balloons' vertical velocities from half to one kilometre average out to less than the theoretical rise, not because the average movement of the air throughout that layer is downwards, but because the system tends to move the balloons towards those particular parts of itself where the movement is downward, *viz.*, the top right quadrant of the whirl.

At first sight it seems a rather depressing result, from the point of view of observational meteorology, to find that when the average figures of several thousand balloons show a retardation in a certain layer, this fact does not denote that the general movement of the air in that layer is downwards, and this apparent unreliability of the evidence may well justify scepticism as to the value of vertical measurements from pilot balloons. I prefer, however, to regard the matter more cheerfully, and put the emphasis not on the fact that the vertical velocities, when considered by themselves alone, appear to give a misleading result, but that progress can be made out of an apparent difficulty, and that by its examination in conjunction with the other connected figures, we can get something more important than mere argument between the bulk averages of a number of varying observations, namely, some idea of the mechanism of convectional movement.

The whirl, that has just been considered, was sketched as if it occurred in otherwise stationary air, such as might occur at Colombo in March or April, when it would approximate to the sea-breeze circulation. Reference was made to the possible assistance of a slight external wind in deciding its direction and assisting its horizontal components, but during the monsoon season we cannot dismiss the external wind as "slight," and must consider the vertical effect of a monsoon drift on its own merits. This must be further sub-divided into two main divisions—first, the effect of change in surface friction on a steady monsoon drift, such as occurs from, say, June to September, and secondly, the effect of variations in the monsoon drift itself, notably when it is adolescent in May.

Consider the effect of a steady SW. monsoon drift reaching Colombo from over the sea. The lower layers are checked slightly by friction over the sea, and rather more by the greater friction over the land. If, then, we have a greater horizontal velocity in these layers west of Colombo than east of it, more air is brought up from the sea than can be carried inland at the same level, and the balance must rise. This will give an ascent at Colombo that is not directly convectional, in the sense in which the whirls described above are convectional. It is, of course, indirectly convectional, since the monsoon itself, if looked at in bulk, is largely a convectional effect.

Reference must now be made to the curves of monthly distribution (Fig. 3). In each month the average velocity from the surface to one kilometre is decidedly less than that up to half a kilometre, and something of the whirl system just described appears to be in action. However, several other activities must be considered as well.

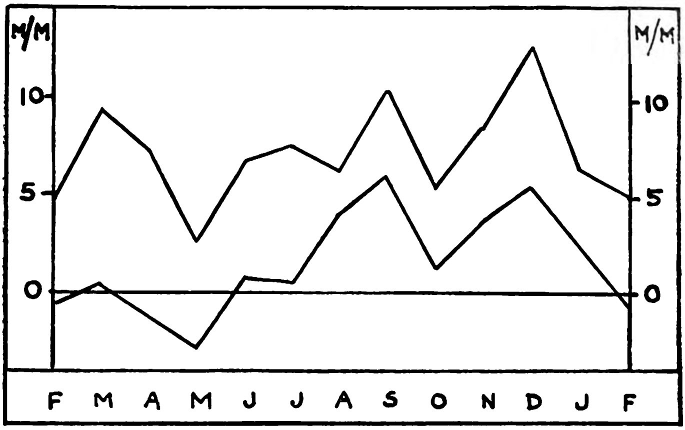

FIG. 3.—Monthly averages of offsets from all flights. Upper curve 0—½ km.; lower curve 0—1 km.

March and April are the months of minimum pressure gradient across the island, and in them the large whirl system appears to be in control without many external complications, and the acceleration of the balloons in the lowest half kilometre is just about balanced by their retardation in the next.

In August and September the vertical velocities both to half, and to a whole, kilometre, are greater, although the amount of sunshine, and simple convection, due to surface heat, is less, and it is suggested that the ascent in these months, though no doubt assisted by local convection of the whirl type, must be explained as in great measure due to the checking of the lower layers of the monsoon just described.

It may be possible to obtain some information as to the mechanism of this checking of the monsoon near the coast line from quite another source. The check and consequent ascent implies a change in density and hence in refractive index of the air as one passes from sea to land, which at Colombo is roughly across the plane of action of the transit instrument as used for clock stars. I have suggested elsewhere[5] the possibility of correlation between the distortion of clock-star observations and convection (as estimated by the number of hours of sunshine) during the monsoon, and though I cannot claim that the existence of this correlation is generally recognised as yet, I am hopeful that before long the differences between time as determined by local clock-star observations and by vernier wireless signals may have afforded yet another example of the co-operation between various branches of science by assisting pilot balloons to report on tropical air currents.

However, leaving such forecasts for the moment, the immediate question is why the ascending effect that shows so strongly in August and September does not show so well in the earlier stages of the monsoon in May and June. In order to answer this let us consider the effect of change in the monsoon strength when it is first establishing itself in, say, May. Quite apart from variations in friction, as between sea and land, the mere existence of any surface friction will result in the strongest advance being in the free air, well above the earth's surface, and from this level down to the surface the strength will ease off.

Similarly the monsoon strength must ease off upwards between its level of maximum velocity and that of the cirro-cumulus which moves from almost the opposite direction.

In the absence of such definite opposition as is provided by surface friction, the fall-off in these regions may be more gradual than on the lower side of the main current, but, without claiming quantitative accuracy, it seems reasonable to think of the advancing monsoon wave front as something of the wedge-shaped type shown in Fig. 5.

The region of maximum strength is certainly not below a kilometre, and the fact that the wave front faces downwards as well as forwards below this height suggests that as it advances it may cause a definite downward effect, which might be mild in the case of a smooth advance of the type shown in Fig. 5, and be rather more irregular in detail, and more marked in its total effect, if the presence of turbulence develops the connection between the advancing wave front and the air in the area into which it is advancing.

It is suggested that the distinctly low points in May on both curves in Fig. 3 are due to this cause, and the suggestion receives further support from Fig. 4.

In Fig. 4 the morning and afternoon observations that were combined in Fig. 3 are plotted separately. Points on the half kilometre curves are (as in Fig. 3) only taken from flights in which the balloon was seen up to at least a kilometre (Table II), but in addition the effect of short flights is shown by dots, unconnected by a curve, giving the average velocity from all flights (Table I).

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[5] *Ceylon Journal of Science*, **1**, Pts. 2 and 3. "Variation of clock stars with wind" and "Longitudinal determination at Colombo."

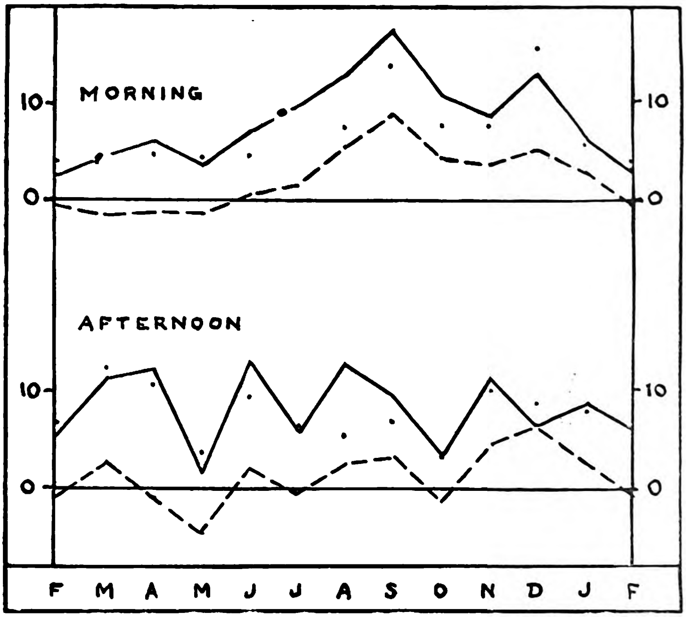

FIG. 4.—Velocity offsets from flights visible to at least one kilometre.
0—½ km. ——— 0—1 km. — — — —
The dots represent offsets from all flights 0—½ km.

We naturally expect convection, and convectional turbulence, to be more marked in the afternoon than in the morning, and Fig. 4 confirms several of the suggestions made above. Thus in March and April, when the simple convectional whirl appears to be the main item, the half kilometre curve is higher in the afternoon than in the morning, and the drop from it to the one kilometre curve is also greater.

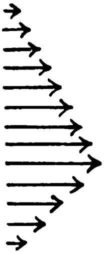

FIG. 5.—Wave front of advancing monsoon.

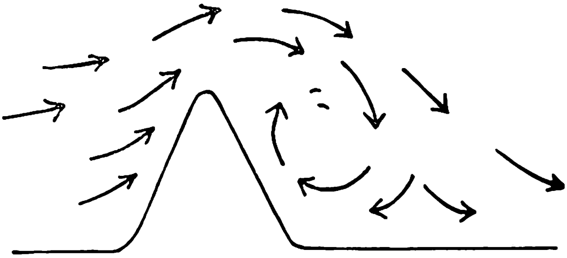

FIG. 6.—Stream lines on the side of hills during the monsoon.

In May we see that the depression of both curves in Fig. 3 is chiefly due to the afternoon flights, confirming the idea that the downward effect of the advance of the adolescent monsoon increases with increased turbulence.

In the discussion of Fig. 5 the point was emphasised that it referred to the monsoon when establishing itself, rather than when fully established. It is not so easy to visualise the process of its collapse, but a decrease in the strength of the main stream after a period of steady monsoon flow, may reasonably be expected to have the converse effect to the increase, though probably not so intense in its action. This possibly explains why the points in September are distinctly higher than those in June.

Another point that requires comment is the way in which the July curves in Fig. 3 show a dip below the otherwise smooth increase from June to September. It will be seen from the dots in Fig. 4 that in July the short flights had practically the same velocity up to half a kilometre as those that were observed up to a kilometre, and hence were used in drawing the curves, whereas in June and August the short flights were slower. The height of lowest cloud is slightly higher in July than June or August,[6] and it is suggested that a number of comparatively slow flights ended in cloud at about a kilometre in all these three months. In June and August these ended for the most part below a kilometre, and their figures contributed to the dots in Fig. 4, and did not contribute to the curves. In July the corresponding flights survived just long enough to reach a kilometre, and hence their results are included with the curves, and serve to depress them, instead of the dots.

In confirmation of the above it may be seen from Tables I and II that in July out of 339 balloons seen to half a kilometre, 200 or about 60 per cent. were seen to a whole kilometre. In June, August and September the corresponding percentages were only 53, 44 and 51 respectively.

With the collapse of the SW. monsoon in October, one might expect something of the inter-monsoon conditions of March and April to reappear in October and November, but with this difference that, whereas in the change from NE. monsoon to SW. monsoon earlier in the year the pressure gradient practically collapses and reappears in the opposite direction, in the change from SW. to NE. monsoon to a considerable extent the gradient persists, but swings round in direction through NW. This means that the large convectional whirls, though important at this period, do not hold the entire field with the completeness that they do in early April. Further, the phrase "NE. monsoon" is hardly descriptive enough for the season that bears that name at Colombo, because during it, and particularly at its commencement, there is a good deal of Northerly and North-westerly wind. The latter is chiefly in the afternoon and involves a component from sea to land, which may explain why Table II and Fig. 4 show greater upward velocities in the afternoon than the morning during November.

However, it is when we come to December that we find something quite different from anything yet discussed. The average vertical velocity in the afternoon in December is numerically as strong above half a kilometre as below it, and only reference to the individual observations from which those averages are obtained will explain this. On three occasions—once in each of three different

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[6] *Ceylon Journal of Science* (Sect. E), **1**, Pt. 1. "On the climate of Western Ceylon," Pl. XIX.

Decembers—the upward velocity from half a kilometre to one kilometre exceeded its theoretical value by over 150 metres per minute. The average of these three flights up to half a kilometre was about 60, while all three were lost sight of in cloud below 2 kilometres. By omitting those three flights the afternoon offset from the surface to one kilometre drops from +6.4 metres per minute for 86 flights to +2.5 for 83.

The fact that three flights can so distort averages makes it desirable to add something about the frequency of similar occurrences in other months. In the seven years' work under discussion there is only one other case of an offset of over 150 metres per minute from a half to one kilometre at Colombo. That was in September, 1922, and its omission would make the September peak on the morning curve in Fig. 4 a trifle less pointed, though still leaving it a distinct peak. It is interesting to find, however, that the comparatively few flights at Diyatalawa (4,000 feet above mean sea level, and on the eastern side of the main range) include two such cases both in June, in which month only three flights out of 300 at Colombo have shown a vertical offset of as much as 50 metres per minute for the whole kilometre, and then only by the lower half doing most of the work. The highest of the three was only 62 metres per minute.

Both Diyatalawa in June, and Colombo in December, can be described as on the lee side of a monsoonal circulation (in support of the latter it may be mentioned that there is a good deal of Easterly wind at 2 kilometres over Colombo in December).[7] In these cases of exceptional velocity between half a kilometre and one kilometre the velocity in the lowest half kilometre, though above average, was not extraordinary, and it seems likely that we have again got the effect of large whirls but this time of a type that should not be described as due to "surface convection" but as due to the inter-action between different strata rolling over each other in different directions largely as eddies in a monsoon current on the lee side of hills. In this connection Fig. 6 is reproduced from a paper on the "General Circulation of the Air over Ceylon,"[8] which appeared in 1922. The diagram in question is an attempt to show the streamlines on the lee side of the hills during the monsoon, and is one of a series dealing with different times of year. That paper contained the following sentence:—"References to upper air movements are purely those deduced from surface observations . . . and it will be interesting to see when the pilot balloon observations are published, how closely they support the suggestions now made." In this particular at least they appear to support them very well.

Besides the cases of exceptional acceleration that have been referred to above, only five other cases are recorded of velocity offsets of as much as 100 metres per minute for the lowest kilometre. Of these, three were in months adjacent to December (two in January, one in November), so may be grouped as at the same season, and one each were in March and April; both of these can be regarded as due to cases in which a whirl was of the ordinary type but of rather larger dimensions than usual, since they both show a high velocity below, as well as above, the half kilometre level. All the above large offsets were cases of acceleration. At the other extreme the slowest offsets were a case of 65 metres per minute below the theoretical ascent in May and one of 55 in July.

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[7] *Ceylon Journal of Science* (Sect. E), **1**, p. 193.

[8] *Bulletins of the Colombo Observatory*, No. 4, 1922.

Special reference is not made in the above to the distribution of specially rapid ascents in the lowest half kilometre that did not persist higher, as these come within the natural scope of the original whirl system. It is worth noticing, however, that while the short flights were, on the whole, slow flights, the reverse was the case in December (Fig. 4).

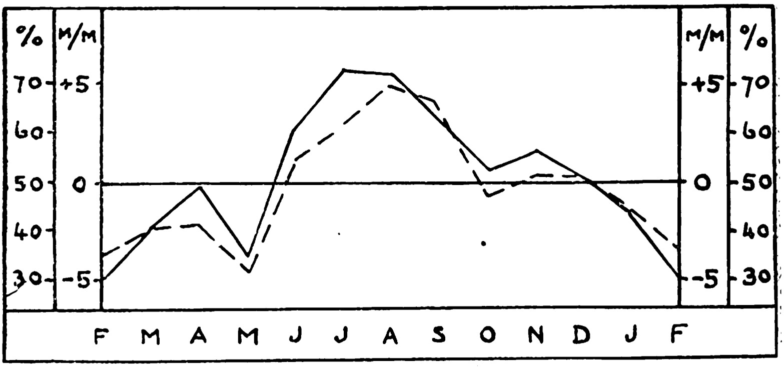

FIG. 7.—Average offsets of velocity from one to two kilometres ————.
Percentage of accelerated flights — — — —

The next curves to be examined are in Fig. 7. They give the average offset of velocity from a height of one kilometre to two, and also the percentage of accelerated flights between these levels. Their smoothness is striking, and may be summarised as acceleration during the SW. monsoon. Apparently this is the lifting effect referred to previously, which may be partly due to simple surface friction, but probably also to the background of hills, since the SW. monsoon at Colombo is often a "WSW." monsoon, and the streamlines certainly point to the main hills, rather than north of them.

The parallelism of the curves of quantity and percentage frequency suggests freedom from violent velocities of the type just referred to at the previous stage in December.

VELOCITIES ABOVE THREE KILOMETRES.

The right hand side of Fig. 1 suggests a continuous increase in vertical velocity from three kilometres upwards which should probably be described as due to general tropical convections rather than the more local convection of the lower layers. As such we should expect its action to be smoother than movements near the surface, and Fig. 1 is certainly smooth up to eleven kilometres, at which height it is drawn from only 15 observations. The single point to the right of this is a mean point depending on 17 observations at various higher altitudes.

In Fig. 8, in which a distribution by months is attempted, the paucity of observations is more serious, and the cloudy SW. monsoon months are grouped in pairs.

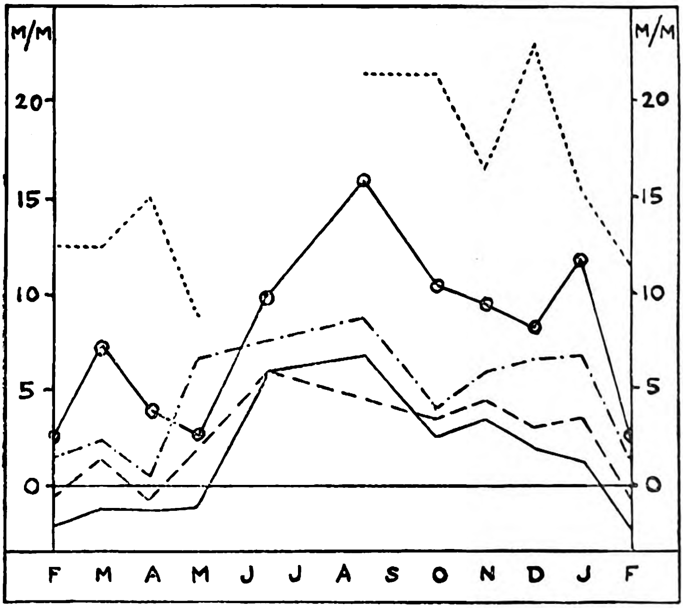

Fig. 8.—Average offsets of velocity from surface to various heights.
0—3 km. ——— 0—4 km. — — — 0—5 km. —.—.—.—
0 to mean of 6, 7 and 8 km. O—O—O—O
0 to mean of 9 km. and above ....

The 3-kilometre curve suggests the influence of the lifting effect of the coast during steady SW. monsoon conditions, which was so emphasised in the layer from one to two kilometres, and it is noteworthy that the 4-kilometre curve, though rather above the curve for 3 kilometres during most of the year, is not so when that monsoon is in full control, though it is distinctly above it in May, when the monsoon is commencing.

The 5-kilometre curve is above both the 3 and 4-kilometre curves in every case, the rise being specially marked in May.

Above 5 kilometres the decrease in the number of observations makes it seem undesirable to show separate curves for each kilometre (though details are available in Table IV), but a curve composed of the means of the readings at 6, 7 and 8 kilometres is given. It shows a marked rise over the curve for 4 kilometres, and in every case but one over the curve for 5. This exception is May. It is possible that the rise of the 4 and 5 kilometre curves in that month is not fortuitous but comes under the scope of the suggestion made on page 373. Presumably at a height of 3 kilometres we are above the level of strongest monsoonal advance, and in May the coming of the monsoon produces an upward move-

TABLE IV.—AVERAGE OFFSETS OF VELOCITY IN M./MIN. FROM THE SURFACE TO VARIOUS HEIGHTS IN KILOMETRES.

The number of flights concerned is shown in brackets after each offset.

Month.	Kilometres.												
	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	>14.
January	+ 1.2 (79)	+ 3.3 (54)	+ 6.8 (38)	+ 11.4 (24)	+ 10.4 (14)	+ 15.3 (9)	+ 15.3 (3)	—	—	—	—	—	—
February	− 2.1 (92)	− 0.6 (68)	+ 1.4 (49)	+ 2.7 (33)	+ 2.7 (22)	+ 1.7 (14)	+ 5.9 (8)	+ 9.0 (5)	+ 10.5 (4)	+ 13.3 (3)	+ 39 (1)	+ 42 (1)	—
March	− 1.3 (101)	+ 1.2 (87)	+ 2.2 (54)	+ 4.2 (36)	+ 8.7 (24)	+ 12.2 (14)	+ 15.8 (6)	+ 9.0 (3)	− 9 (1)	—	—	—	—
April	− 1.3 (80)	− 0.8 (67)	+ 0.3 (32)	+ 2.8 (20)	+ 4.8 (11)	+ 6.0 (6)	+ 12.0 (2)	+ 18.0 (2)	—	—	—	—	—
May	− 1.1 (47)	+ 1.9 (27)	+ 6.5 (20)	+ 3.5 (13)	− 1.0 (7)	+ 6.0 (3)	+ 3.0 (2)	+ 4.0 (2)	+ 13 (1)	+ 7 (1)	+ 7 (1)	+ 6 (1)	+ 16.7 (3)
June	+ 3.0 (6)	+ 3.3 (3)	+ 10.5 (2)	+ 8.5 (2)	+ 12 (1)	—	—	—	—	—	—	—	—
July	+ 7.0 (19)	+ 7.0 (7)	+ 6.0 (4)	+ 9.3 (3)	+ 10.5 (2)	—	—	—	—	—	—	—	—
August	+ 5.0 (9)	+ 3.0 (3)	+ 7.5 (2)	—	+ 5 (1)	+ 24 (1)	+ 16 (1)	+ 22 (1)	—	—	—	—	—
September	+ 7.0 (27)	+ 5.0 (11)	+ 9.2 (4)	+ 11.7 (3)	+ 18.7 (3)	+ 23 (1)	+ 26 (1)	—	—	—	—	—	—
October	+ 2.5 (100)	+ 3.3 (71)	+ 4.0 (45)	+ 5.8 (27)	+ 13.3 (19)	+ 15.2 (15)	+ 16.3 (11)	+ 22.1 (9)	+ 24.6 (8)	+ 28.0 (2)	+ 25.3 (3)	+ 18 (1)	—
November	+ 3.4 (108)	+ 4.2 (79)	+ 5.8 (49)	+ 8.5 (33)	+ 9.3 (17)	+ 12.7 (12)	+ 16.8 (5)	+ 16.0 (3)	—	—	—	—	—
December	+ 1.9 (98)	+ 3.0 (67)	+ 6.5 (50)	+ 6.8 (24)	+ 8.1 (16)	+ 10.8 (12)	+ 24.0 (2)	+ 27 (1)	+ 23 (1)	—	—	—	—
All	+ 1.1 (766)	+ 2.1 (544)	+ 4.2 (349)	+ 5.9 (218)	+ 8.0 (137)	+ 10.8 (87)	+ 13.8 (41)	+ 15.8 (26)	+ 17.7 (15)	+ 17.2 (6)	+ 24.4 (5)	+ 22.0 (3)	+ 16.7 (3)

ment between the heights of 3 and 5 kilometres corresponding to the downward one that explains the low points for May in the curves in Figs. 3 and 4. If this is so there is nothing surprising in its not persisting to 7 kilometres since cirro-cumulus clouds appear to be above the monsoon.[9]

Above the curve for 6, 7 and 8 kilometres is one from still higher readings—largely, but not exclusively, at 9 or 10 kilometres. This is in every case well above the last one, the only months that contribute no data being June and July. The face value of these latter curves thus points to a strong and increasing upward movement over Ceylon up to at least 10 kilometres, with no indication of decrease there but merely a cessation of information.

I have worded the last sentence guardedly, because I feel that there are several difficulties that must be referred to, and reassurances given, before readings at such heights can be accepted.

In the first place a single tail reading at an altitude of 10 kilometres may be very much in error, and for that reason the determinations used in this paper at such heights are from smoothed curves. The actual altitudes derived from each observation have been plotted (altitude against time) and values at the higher levels usually appear in a series of ascending steps, the results of several consecutive observations in each step, in which the tail appeared to be of the same angular length, often appearing as a slight descent, although allowing a smooth curve of ascent to be drawn through the middle of successive steps. Even so there are a good many flights with regard to which it was felt that the vertical height was known well enough for them to be used for horizontal velocities, but which have had to be discarded for use in this paper, in which a higher degree of vertical accuracy was required.

Then on the question of accuracy of the theodolites, it is clear that unevenness of the graduations that would be immaterial at 2 kilometres might be serious at 10. The risk is admitted, but on the whole the indications are encouraging. Thus at 9 kilometres the apparent offset is over 13 metres per minute or about 10 per cent. of the average theoretical velocity. A slight calibration error is possible, but hardly one of 10 per cent. Another important point is that if a particular altitude had usually been reached at about the same apparent tail length, it would be hard to distinguish whether an increase in upward velocity found there might not be due to an under-estimate of the tail length. Thanks to the variety of the horizontal paths of the balloons the tail lengths corresponding to a particular altitude vary greatly on different occasions and so minimise this risk.

A point on which I admit to a feeling of more uncertainty is as to how far we can assume that the formula for theoretical rise holds good. The value of q in the Dines formula is not a constant for balloons of different sizes, but is larger for big balloons than small ones. As a balloon increases in diameter as it ascends, it is possible that even for a particular balloon we ought not to take q as a constant, but as a varying coefficient, that increases as the balloon ascends and grows. Further, in a long flight there is time for appreciable leakage, and there is also the point of rate of temperature adjustment.

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[9] *Bulletins of the Colombo Observatory*, No. 5, 1924.

Thus at the beginning of a flight both the surface of the balloon and the surface of the ground are warmed by radiation, and they warm the adjacent gases. When the balloon is at a height of several kilometres its solid, if thin, envelope can accept heat by radiation more readily than the air around it, and as the gas inside is not very far from the envelope, and has not been far from it during the ascent, it may be hotter than the free air outside. This point suggests the possibility of an increased rate of rise, so that it may not be possible to attribute all of the strong ascent shown in Fig. 1 to atmospheric circulation. If there is error on this account it is possible that its effects would, to a large extent, cancel out in comparing ascents in different places, and hence comparison with similar observations in other parts of the world appears to be required for the next step in the analysis.

DISCUSSION.

Mr. J. H. Field said: The present paper concerns itself with one of the more delicate features of the long series of valuable balloon flights in Ceylon, which Mr. Bamford has carried out and examined with his usual thoroughness. As a result of this part of his examination he concludes that systematic vertical currents characterise the winds over Colombo, and he offers a physical explanation of them. The means of measurement used do not, however, seem to me to be critical enough to allow of the fine deductions made, and I should be inclined to suspect that a part at least of the results may be traceable to this comparative want of precision, which is inseparable from work with a single theodolite and a hanging balloon tail. It is true that the method has been increasingly used for pilot-balloon observation since workers in India developed it in 1908 for general purposes there; but it is less suitable than other methods when the finer details of air currents are to be examined, even if all precautions (*Indian Met. Mem.*, **24**, part 5, pp. 146-151), have been taken against error. The tail baseline is necessarily short, and for precise results a correction, difficult to determine accurately, has to be applied when the wind conditions cause the tail to hang out of the vertical. It may be taken as certain that the tail never actually oscillates like a swinging pendulum; its air resistance forbids: but it does lie at an angle to the vertical in all cases where a difference of wind velocity exists between the balloon level and that of the tissue-paper flag at the bottom of the tail. In Agra the steady slopes of the standard form of tail in measured velocity gradients were determined with some care, by picking out from a long series of measurements of tail angles on balloons rising in free air those which subsequent plottings of trajectories showed to be on courses nearly at right angles to the line of sight, so that the measured angles were the actual full value of the angles of slope in the known velocity gradients. Mr. Bamford's 20m. tail with its proportionately smaller end flag should lie at approximately similar angles. The vertical air current velocities deduced by Mr. Bamford, even for the very marked case of the lowest kilometre, are small in comparison with the normal rate of rise of a pilot balloon. If the normal is 150m. per minute the excess ascent and descent values do not amount in this stratum to more than 5 per cent. Now, a balloon will frequently show an altitude angle of 45° or more in these early stages, and at 45° the tail need only lie at a slope somewhat less than 3° from the vertical in the plane of sight to introduce, by foreshortening, a spurious excess of balloon height and of rate of ascent equal to the figures for Mr. Bamford's first ½km., and correspondingly in the reverse direction from ½km. to 1km. to offer spuriously a downward current such as that of his diagram. This angle of slope of the Indian tail is given by a difference of horizontal wind velocity of 0.25 m./s. per 100m. of rise in the air, a value frequently exceeded for minutes at a time as the balloon ascends. That these spurious divergencies occur in practice is constantly noticed on height-time curves: most of the well-marked gradients of wind strength between balloon and tail-end will be found to carry the height determination of their observations to the corresponding side of the mean curve of rate of ascent for the individual balloon, and a considerable series of such points lying away on the same side of the height-time line may occur consecutively. Consequently in India it is in general only the mean rate of rise shown over several minutes' interval that is trusted in using the tail method without making corrections for slope, and not, in general, the finer details of the flight. A further but smaller matter of doubt is how a 20m. tail can be measured in normal practice with even 20 per cent. accuracy at 10km. height. The balloon will be, say, 15km. away in the line of sight, and the tail will measure barely 1⅓ thousandths of a radian. Perhaps during weather suitable for these long distances Mr. Bamford used a very much longer tail, but even a 100m. tail hanging truly vertically would still have an uncertainty of about 5 per cent.

In reading the advance proof of this paper I have thought that a simple experimental method might be tried to detect the upper and lower limits of vertical currents. It is hard to judge beforehand whether the method would prove feasible, but if I were still in harness I should be inclined to try it, and Mr. Bamford might perhaps like to do so. Take two balloons, one larger than the other, and connect them by a 10m. cord or fine metal chain of appreciable weight, say, 2g. per metre length. Fill both, and handicap the larger with a weight to make the two independent rates of rise approximately equal; then liberate the system. If the ascensional rates are equal the balloons will rise together and retain their original relative vertical positions with the two limbs of the bight of chain hanging down between them; and they will not straggle much horizontally, for the divided weight of the chain will make them lie snug. If the ascensional rates are not correctly adjusted at release, the faster balloon will at once handicap itself by assuming more chain weight and the system will thereafter rise steadily. But as soon as a vertical air current is met, the smaller balloon will prove the more lively and will respond momentarily by shooting up ahead or dropping behind the other, according to the sign of the vertical current; and when the larger balloon has itself accepted the new velocity, the smaller balloon, or indicator, will sidle back to its original relative position, ready set to respond again as an indicator to the next change of vertical current strength. Variations of horizontal air currents should probably be similarly detectable.

In cases like Mr. Bamford's it is possible that the paired balloons might give information of value, if small-scale turbulence did not intervene to muddle the conclusions. Doubtless the best chain weight per metre might take trouble to find; it must be large enough to ensure an equilibrium between balloons without letting the bight of chain be drawn out straight, yet small enough to allow liveliness of the indicator balloon.

Sir GILBERT WALKER welcomed any investigation that could throw light on the unstable conditions which arise above strongly heated ground. He thought that the descent of air after it had risen to some height would occur if the air rose in columns and descended between the columns just as well as it did in Mr. Bamford's horizontal vortex.

Mr. L. H. G. DINES: The author has referred several times in his paper to general tropical convection, and especially in relation to the apparent upward velocity of the air above five kilometres. It is evident, however, that the average value of the vertical velocity in any general tropical convection must be very small indeed compared with the ten metres per minute and over found in this case. It seems a great deal more likely that the real reason for these apparent upward velocities above five kilometres is to be found in an error in the pilot-balloon formula as the balloon expands, which we have, in fact, every reason to expect. The author refers to an earlier paper in verification of the formula, but a reference to this paper does not help us much. The data on which it was based showed an agreement between the theoretical velocity of the formula and that found by the tail method; why was not the vertical velocity said to be due to convection operative in that case? One can hardly have it both ways. It would be instructive if the author could say something more about the remarkable type of convection which he has postulated; his typical whirl seems to be like a large horizontal sausage about one kilometre in diameter. It is a good deal easier to imagine such a thing with the wind blowing at right angles to the coastline than when it is blowing parallel to it. Apparently, however, the effect was found in all seasons of the year, and presumably, therefore, with winds from all directions.

Mr. A. J. BAMFORD replied: With regard to Mr. Field's comments, I am only too conscious of the limitations of the accuracy of the tail method. There are, however, several reasons that make me feel that these troubles, on account of non-vertical tails, are not as bad as may appear at first glance. Admittedly the results that I have attributed to vertical currents could be obtained if the tails consistently leant towards the observer in the first half kilometre, and away from him in the next. This would occur if the horizontal movement remained unchanged in direction, and its intensity increased from the surface to half a kilometre, and decreased above that height, but if its occurrence was common enough to upset the main distribution of average vertical movements, it would be common enough to show more than it does in the roses of average horizontal movement. [These have not been reproduced in this paper, but are published in the *Ceylon Journal of Science*, Section E, Vol. I., Pt. 3].

The use of a 20m. tail rather than a longer one was adopted intentionally after correspondence with several other meteorologists, notably Mr. Field himself, who was kind enough to supply me with a good deal of information when I was starting upper-air work in Ceylon. In an atmosphere where horizontal movement increased uniformly with height the slopes of 20m. and 100m. tails might be similar, but if, as seems likely, turbulence makes the transition more erratic there will be many cases where a balloon and tail, 20m. apart, will be sensibly under the same conditions, when the same would not be true if they were 100m. apart. An obvious comment on this is that if a discontinuity did occur within 20m. of the balloon the short tail would be more deflected than a long one, but it must be remembered that a curve of apparent height against time is plotted for every ascent, and it is the smoothed values from these points that are used in this paper. A severe deflection such as might arise from a discontinuity close to the balloon would show on the curve as an abnormality, and disappear in the adopted smoothed value. Several other points suggest that the obliqueness of tails, though a regrettable cause of error, does not upset the main contention. Thus similar results are referred to in the paper as having been found over Palestine, where tails were not used, but an army rangefinder, and since writing this paper I have had the pleasure of reading Dr. Kidson's paper on a similar subject, where again with a rangefinder, not tails, a vertical acceleration is found near the surface and succeeded by a retardation a little higher up. [These results are comparable in type, but not in numerical detail, as he takes a slightly higher value for q in the Dines formula].

With regard to the use of a 20m. tail at high altitudes, it is admittedly impossible to deduce much from a single reading. Several successive observations usually give the same apparent tail length and groups of similar, or even descending, values of the altitude result. Hence we cannot compare one observation with the next, but we can draw a reasonable mean through the centres of successive groups. This point was illustrated in the *Meteorological Magazine* for 1925 in a diagram sent by Mr. H. Jameson.

I hope it will be possible to carry out the experiment of linked balloons after my return to Colombo, when I can also apply another test regarding tail inclination by examining the difference in altitudes derived simultaneously by measurement of short tails and of balloon diameters near the surface—the former are liable to over-estimate and the latter (owing to expansion) to under-estimate. The difference should therefore give an outside limit to either error.

With regard to Sir Gilbert Walker's point, it must be remembered that the circular shape is avowedly a "simplest case" such as might occur in otherwise still air. In general there are disturbing influences and the circular diagram may have to be drawn out to an ellipse with its major axis horizontal, or flattened to one with its major axis vertical, which in the limiting case might even be described as a pair of ascending and descending columns.

With regard to Mr. Dines' first point, I can only call attention to the very cautious wording of the last two paragraphs of my paper. With regard to Bulletin No. 5 it is a fact that the average rate of ascent to 8-10km. over the whole of the last seven years has been appreciably greater than the average during the first of those years alone.

In conversation, after the conclusion, of the formal meeting, Dr. Whipple mentioned that the whirl allowed for cases in which the velocities in the first and second half kilometres were successively $++$, $+-$, $--$, but hardly any $-+$, and that further examination of the percentages in Tables I. and II. might be instructive. Such analysis has now been made, and shows that, though the sequence $-+$ does occur, it is by far the least frequent of the four.

STUDIES ON THE RHONE GLACIER, 1927
THE RELATIONSHIP BETWEEN THE AVERAGE AIR TEMPERATURE AND THE RATE OF MELTING OF THE SURFACE OF THE GLACIER

By GEORGE SLATER, D.Sc., D.I.C., A.R.C.S.

(Communicated by Sir GILBERT WALKER, C.S.I., F.R.S.)

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1.—INTRODUCTION.

Observations in Spitsbergen in the summer of 1921 suggested to the author a simple tentative relationship between the average air temperature and the rate of melting of the Nordenskiöld Glacier [5][1]. This relationship may be expressed as $M = \frac{1}{2}(t - 32\text{ F.})$ where M = thickness (in feet) of ice melted per month (30 days), and t = average monthly temperature (in °F.). In other words, .2 inches of ice were melted per day for each degree (F.) above the freezing point, under normal atmospheric conditions, wind and rain producing deviations from the normal.

This relationship was supported by observations of the rate of retreat of the glacier during the previous 10 years coupled with the records of temperatures for the same period determined at the Green Harbour Meteorological Station. The relationship was again strikingly supported two years later, the retreat of the ice on this occasion being measured by Dr. Longstaff, and the records of temperature determined from daily records at the Meteorological Office at South Kensington.

With the object of further testing the truth of this tentative law, observations were conducted on the Rhone Glacier 1927, over a period of twenty days.

2.—PREVIOUS OBSERVATIONS ON THE ABLATION OF GLACIERS.

Even on empirical grounds the melting of a glacier is a meteorological question. The rate of melting varies with the seasons, and is greatest towards the end of the summer months. Forbes [1], for example, in 1842 noted that the surface of a glacier was lowered 30 feet in a few months of a very hot summer, and he attributes this abnormal rate to the effects of direct solar heat, contact of warm air, and the washing of rain.

Nevertheless, in spite of the amount of work which has since been accomplished on the ablation of glaciers in Arctic, Norwegian and Alpine areas, only indirect correlations with the climatic factor have been attempted. These correlations fall under two headings—(1) altitude, and (2) latitude.

(1) *Altitude.*—Mercanton shows in a table the relationship between the rate of melting of the Rhone Glacier and altitude [4]. He therefore came to the following conclusion:—

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[1] Numbers in square brackets refer to the bibliography at the end.

> " L'ablation décroit quand l'altitude croît; son décroissement n'est pas proportionnel à l'accroissement de l'altitude, mais est plus lent."

The almost entire absence of records of temperature for the area of the Rhone Glacier is a regrettable omission of the valuable memoir on this classical glacier.

(2) *Latitude.*—The relationship between ablation of ice at 400 m. below the snow line and latitude has been demonstrated in tables by Hess. A revised table by Hoel [3] is as follows:—

1. Spitsbergen 79° 0′ N., annual rate of ablation = 1.4 m.
2. Greenland 70° 30′ N., annual rate of ablation = 2.2 m.
3. Scandinavia 67° 20′ N., annual rate of ablation = 2.5-3.0 m. (mean 2.75 m.).
4. The Alps 40° 0′ N., annual rate of ablation = 4.0 m.

The Glaciers of Savoy [2].—During the present century much detailed work has been accomplished on the glaciers of Savoy. As regards the rate of ablation of the glaciers, French workers lay increasing stress on the importance of temperature as the dominant factor. The rate of variation of temperature with altitude was found to be 1°C. for 130 m. in summer, or 1°C. for 230 m. in winter, giving a yearly mean of 1°C. for 180 m. The importance of establishing meteorological stations adjacent to particular glaciers and at different altitudes is also emphasised. Such stations are necessary for the purpose of obtaining monthly records of temperature. The present author maintains, however, that the only reliable records of air temperature available for comparison with the rate of ablation, in a mountainous district, are those recorded at the ablation station selected on the ice.

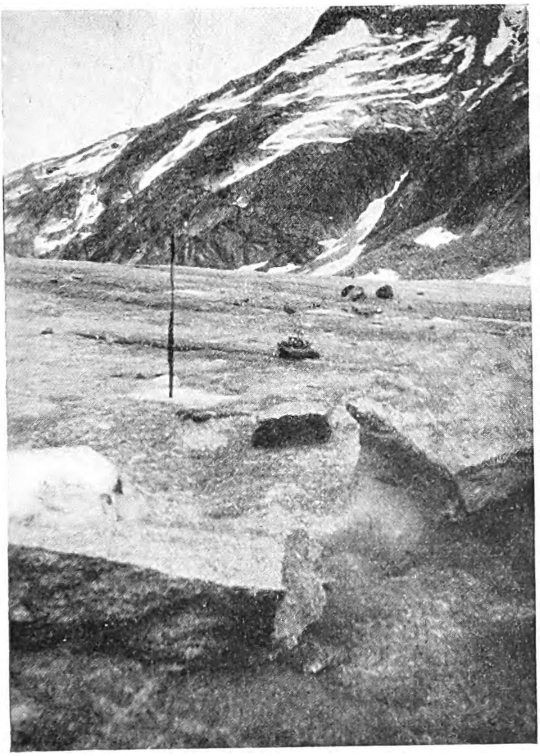
From the point of view of the present paper the records of temperatures and rates of ablation of the glaciers of Savoy, some of which cover long periods of time, lose much of their value owing to lack of direct correlation between the two factors [2].

3.—POSITION OF ABLATION STATION OF THE RHONE GLACIER.

The point selected for the ablation station was in the south-eastern embayment of the Rhone Glacier north of the Belvedere Hotel, and a little north-west of the termination of the path which leads to the Fort and the Furka Path (Plate IX.). This position was easily accessible and was sufficiently isolated to be beyond the influence of heat radiated from the eastern side of the glacier.

4.—METHOD EMPLOYED.

The usual method was adopted for the measurement of the amount of ice melted at a given period. A hole three feet deep was bored with a hand auger and a wooden stake inserted, the level of the surface of the ice being marked by a red band of sealing-wax which had been dissolved in methylated spirit and was then painted on the stake. At a distance of about a foot above the level of the ice a standardised maximum and minimum thermometer (Negretti & Zambra) was suspended, facing north, and protected from the sun. The method adopted by Forbes of inserting a rod across a crevasse some distance below the level of the ice was considered, but abandoned as impracticable.



Photograph by G. Slater.

South-Eastern Embayment of the Rhone Glacier. Ablation Station, Rhone Glacier, July 27 to August 15, 1927.

Before commencing the daily recording of the temperature and amount of melting of the ice, an afternoon was spent in noting the hourly temperatures over a period of five hours. The agreement of the results with the formula showed the necessity of obtaining hourly records in order to obtain precise results. In view of other investigations this was impracticable. As the average of the maximum and minimum temperatures gave too high a value for the average air temperature, some other record was necessary. The most suitable time for the taking of an additional record was about the hour of noon.

5.—Zürich Air Temperatures.

An inspection of the tables of Zürich air temperatures (*Das Klima der Schweiz*, 1864-1900) confirms this view, as shown by the following selected table of figures:—

Zürich Air Temperatures (August).

Max. temp.	Noon temp.	Min. temp.	Mean of 24 hours.
22.52	21.48	13.08	17.49

If the mean between the maximum and minimum temperatures be taken, the figure is 17.8, a mean .31 higher than the hourly mean. If, however, the mean be taken of the maximum and noon temperature and the resulting figure 22 be averaged with the minimum temperature, the resulting mean is 17.54, or only .05 above the mean of 24 hours.

Assuming the maximum temperature during August to occur in the afternoon at 2 p.m., the average between the noon and maximum temperatures gives a point of greater precision for the crest of the temperature curve, which is lowered.

6.—Results Obtained.

The results obtained are indicated in Table I.; the average daily temperatures and rates of melting of the ice are plotted in Fig. 1. The records given in Table I. were taken about noon of each day. As a check to these figures, the noon temperature of the previous day was averaged with the maximum of the succeeding day, and this figure again averaged with the corresponding minimum temperature. The average temperature for twenty days by this method was 40.8°F., and the theoretical amount of melting 35.32 inches, as compared with 40.8°F. and 35.58 inches respectively of Table I.

The most striking fact about the table is the confirmation of the tentative law of ablation. The average temperature was 40.8°F. or +8.8°F. above the freezing point. Reckoning .2 inches of ice to be melted per day per degree, the amount of ice melted in twenty days would be 35.2 inches, a result which agrees with the actual amount of ice melted during this period.

7.—Sources of Error.

In view of the variable factors involved, this result was hardly to be expected.. The variable factors are most apparent by examination of the columns for a particular day.

TABLE I.—DAILY TEMPERATURES AND RATE OF MELTING OF THE ICE OF THE RHONE GLACIER, JULY 26—AUGUST 15, 1927.

Date.	I. Maximum temperature.	II. Average noon temperature.	III. Average of I. and II.	IV. Minimum temperature.	V. Average of III. and IV.	VI. Actual rate of melting (inches above fixed point).		VII. Daily rate of melting (inches).	VIII. Theoretical rate of melting based on temperature. (V.—32) × ·2.		
	°F.	°F.	°F.	°F.	°F.						
July 26	49.0	44.6	46.8	—	—	—		—		—	
,, 27	49.0	44.5	46.75	34.0	40.37	1.3		1.3		1.67	
,, 28	54.0	41.5	47 75	34.5	41.12	3.3		2.0		1.82	Rain.
,, 29	48.5	40.0	44.25	35.0	39.62	5.5		2.2		1.52	
,, 30	48.75	40.0	44.37	34.5	39.43	7.0		1.5		1.48	
,, 31	49.5	46.0	47.50	34.0	40.75	*9.0*	*9.0*	2.0	*8.24*	*1.75*	
Aug. 1	51.0	46.0	48.50	36.0	42.25	11.0		2.0		2.05	
,, 2	51.0	43.0	47.0	36.5	41.75	13.2		2.2		1.95	
,, 3	48.0	44.0	46.0	34.25	40.12	14.6		1.4		1.62	Rain.
,, 4	52.25	44.0	48.17	34.0	41.68	16.0		1.4		1.81	Spongy ice.
,, 5	53.0	46.0	49.5	33.5	41.5	*18.5*	*9.5*	2.5	*9.33*	*1.9*	Dry, warm wind.
,, 6	53.5	47.25	50.37	36.0	43.18	21.2		2.7		2.23	Rain.
,, 7	51.0	47.0	49.0	36.0	42.5	23 5		2.3		2.1	Rain at 4.20.
,, 8	51.0	51.75	51.37	36.5	43.93	25.5		2.0		2.38	Rain.
,, 9	53.0	39.5	46.25	33.5	39.87	27.3		1.8		1.57	Rain.
,, 10	48.5	42.25	45.37	32.5	38.93	*28.4*	*9.9*	1.1	*9.86*	*1.58*	
,, 11	50.0	45.0	47.5	33.75	40.62	29.7		1.3		1.72	
,, 12	55.5	40.75	48.12	34.5	41.31	31 0		1.3		1.86	Rain.
,, 13	48.0	41.0	44.5	33.0	38.75	32.7		1.7		1.35	
,, 14	50.0	45.5	47.75	33.0	40.37	34.1		1.4		1.67	
,, 15	49.0	40.0	44.5	35.0	39.75	35.2	*6.8*	1.1	*8.15*	*1.55*	Rain.
Mean -	50.6	43.79	47.2	34.5	40.8	35.2		35.2		35.58	

FINAL RESULT = + 8.8° × .2 × 20 = 35.2 inches.

Discrepancies due to errors of observation between the actual rate of melting and the estimated rate based on temperature can be explained as follows:—

(1) *Average Noon Temperature.*—This figure is based on the average of temperatures taken about the hour of noon. Nothing short of hourly records will suffice for the true estimation of the average day temperatures. Hence the average temperatures of column V. are approximate also. Nevertheless, if the estimation of .2 inches of melting per degree above the freezing point be applied to these figures, the discrepancy between the results and the actual amount of melting suggests that the temperature error is only one or two degrees.

(2) *Estimation of daily rate of melting.*—The measurements of the daily rate of melting of the ice were all taken from the same fixed point of the staff in order to obviate cumulative error. In actual practice it was found difficult to measure accurately per day the amount of melting to the degree of accuracy aimed at, *i.e.*, to tenths of an inch, the method adopted by Mercanton of measuring to the nearest centimetre appearing more practicable. One source of difficulty was the removal of the interstitial ice between ice granules, another the " spongy " or cellular structure of the surface of the ice after rain. Occasionally, however, as for example after a dry warm wind, the surface of the ice became level. If, however, longer periods were taken, accurate measurements of the rate of melting could be made.

On the whole, monthly periods of measurement of the rate of melting, coupled with daily records of temperature, give the best results.

8.—VARIABLE FACTORS.

Analysis of the results as plotted on the Graph (Fig. 1).—The results shown in the table can be better appreciated by referring to the graphs (Fig. 1). These graphs show respectively:—

(*a*) The actual rate of melting.
(*b*) The theoretical rate based on the assumption that .2 inches of ice is melted for each degree of average daily temperature.
(*c*) A straight line graph showing an average rate of melting of 1.8 inches a day.
(*d*) A temperature graph.

The general relationship between the rate of melting and the air temperature is shown in the graph (Fig. 1) by comparing the two curves A B C D and A′ B′ C′ D′, a rise in temperature being followed by an increase in the rate of melting. This increase, however, is in excess of the theoretical amount of melting based on the temperature alone. This fact is seen in the graph by comparing the curve A′ B′ C′ D′ with the broken curve, more especially between the dates August 5th-9th (Fig. 1). This excess in the rate of melting is presumably due to the positive effects of variable factors such as a warm dry wind and warm rain. The succeeding decrease in the rate of melting may also be explained as being due to the negative effect of chilled water protecting the surface of the ice

from the air temperature. There is a general compensation, however, between the two factors.

The figures given in columns V. and VII. of Table I. have been plotted in the two graphs shown in Fig. 2. The maxima of the curves are respectively marked A B C D and A′ B′ C′ D′.

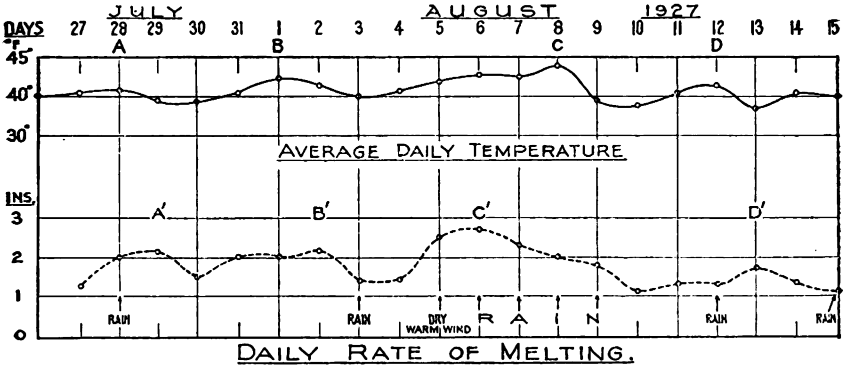


FIG. 2.

It will be noted that the maxima of the curve A′ B′ and D′ occur in point of time one day later than those of the corresponding curve A B and D. This "lag" may be attributed to the spongy condition of the ice, as measurements of the rate of melting could only be made to the surface of the ice. The position of the apex C′ is a measure of the marked amount of evaporation of the surface of the ice caused by the warm dry wind.

A comparison between the two curves supports the view that air temperature is the dominant factor in the melting of the surface ice of the glacier.

With this view Sir Gilbert T. Walker, to whom I showed the paper, agrees; he remarks: "The variations from day to day indicate a relationship between the melting and the temperature of the same order of magnitude as is derived from the total melting in the period." He suggests further that "the temperature of the ice below the surface must remain at the freezing point, so that, apart from heating by the sun's radiation, the melting must turn on the temperature gradient of the air close to the ice surface. This will clearly be affected by wind, and in future work it might be well to measure the temperature, if possible, at a small constant height above the ice." (March 18, 1929.)

9.—GENERAL CONCLUSIONS.

The results obtained tend to show that there is a general "averaging out." of the variable factors.

A monthly period would appear to be the most suitable for estimating the amount of ablation and correlating this amount with the average daily temperatures. The slight variations in the minimum temperatures and the form of the temperature curves suggest that hourly temperatures need only be taken during the day and not for the whole 24 hours. If this is impracticable, then the method adopted in the present investigation would appear practicable over monthly periods.

For the Rhone Glacier it is essential that there should be a meteorological station. Possibly at the Fort, adjacent to the Belvedere Hotel, an ablation station fixed on the glacier and provided with a maximum and minimum thermometer could be visited daily by an observer. The rapid rate of melting of the Rhone Glacier suggests the possibility of the removal of the magnificent ice cascade at some not very distant date. The rate of melting at the base of the cascade where the River Rhone emerges must be considerably higher than that at the ablation station selected by the author. Exact records of temperature and ablation are therefore necessary in order to form an estimate of the future available water supply due to the melting of ice above the cascade.

Reviewing the Rhone Glacier evidence as a whole, it is claimed that the tentative relationship between the average air temperature and the rate of melting of the ice has been substantiated. The elaboration of this law must be left to others more favourably situated for investigation of modern glaciers. Regional surveys of the more general aspects of climate have been dealt with by Simpson and other meteorologists [6].

The application of the law of ablation to the problems of Pleistocene Glaciation is of interest.

Interglacial Periods, which are clearly established in several areas, point to a regional amelioration of climatic conditions. Hence during these periods there was a marked retardation in the accumulation of ice and snow in the gathering grounds. Under such conditions the rate of ablation would be such that regional accumulations of ice from 1,000 to 2,000 feet in thickness could be removed in a period of only a few centuries. With the average known rate of movement of ice, this rapid removal is in striking contrast to the time required for ice to overwhelm regional areas, a period which must be reckoned in thousands of years.

10.—CONCLUSION.

In conclusion the author expresses his thanks to Prof. W. W. Watts for facilities for the working out of the results in the Geological Department of the Imperial College of Science, London.

The expenses of this investigation were defrayed by a Government Grant of the Royal Society, for which the author expresses his thanks.

11.—SUMMARY.

Observations in Spitsbergen, 1921, suggested to the author the following tentative relationship between the average air temperature and the rate of melting of the ice:—

$$M = \frac{t - 32°\text{F.}}{2}$$

where M = thickness (in feet) of ice melted per month (30 days) and t = average monthly temperature (°F.)

This would become .2 inches of ice melted per day for each degree (F.) above the freezing point under normal atmospheric conditions, wind and rain producing deviations from the normal. With the object of testing this relationship further, observations were conducted on the Rhone Glacier in 1927 over a period of twenty days. A hole 3 feet deep was bored in the ice and a rod inserted from which a shaded standardised maximum and minimum thermometer was suspended. It was found that when hourly records of temperature were recorded the relationship given above was corroborated. As the recording of hourly temperatures, however, was impracticable, late morning or early afternoon temperatures only were recorded, in addition to the maximum and minimum.

An inspection of the tables of Zürich air temperatures (*Das Klima der Schweiz*, 1864-1900) shows that the average of the maximum and minimum temperatures gives too high a value to the summer mean, whereas if the mean between the noon and maximum temperatures be first obtained, and then the mean calculated between this figure and the minimum temperature, the approximation to the true mean is more correct. This method was accordingly adopted. The average temperatures (July 26 to August 15) were as follows:—Maximum 50.6°F., minimum 34.5°F., noon 43.79°F. giving a daily average of 8.8°F. above zero. Assuming the rate of .2 inches of ice melted per day for each degree, the total amount melted would be 35.2 inches, a figure which is confirmed by actual measurement.

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DISCUSSION.

Sir GILBERT WALKER thought it interesting that, in spite of the part played by wind in increasing evaporation, the effect of temperature should be equally shown in the integral over a period and in the changes during the period.

DISCUSSION OF MEMOIRS.

D. BRUNT AND C. K. M. DOUGLAS: THE MODIFICATION OF THE STROPHIC BALANCE FOR CHANGING PRESSURE DISTRIBUTION, AND ITS EFFECT ON RAINFALL.

[Vol. 3, No. 22. Published September 1928—Read May 29, 1929.]

SUMMARY.

We have given an equation in which the effect of changing pressure distribution, the curvature of the path of air, and acceleration of the air, are shown separately. Reasons are put forward showing that in certain cases the effect of the changing pressure is larger than the other two terms mentioned, so that an estimate of the deviation of the wind from the geostrophic wind can be derived from an isallobaric chart. This chart should, strictly speaking, be based on instantaneous changes of pressure. The occurrence of rain in isallobaric lows, and of fine weather in isallobaric highs, is attributed to the effects of convergence or divergence over these regions of the deviations from geostrophic wind. Similar arguments hold for rainfall at fronts. Examples are given supporting these views, and showing also that the motion of the front itself may differ from the motion computed from consideration of geostrophic wind alone. Both direct measurements of the changes of pressure, and also deductions from rates of rainfall and the movements of the fronts, indicate that deviations from gradient winds at the 600-metre level ranging up to 5 m/s. are quite common, while in extreme cases the figure may be appreciably greater. It is shown that a convergence of 5 m/s. over a circle of radius 200 km. will give rain of about 4 mm. per hour, which would be classed as heavy rain. In Appendix I. we give a computation of the effect of friction in producing rain, showing that friction can in general produce only light rain, or at most a narrow band of heavier rain along a cold front, with very light rain behind it. In Appendix II. we show that the effect of turbulence in a smoothed sloping surface of discontinuity is to cause convergence in the lower layers.

DISCUSSION.

Sir Napier Shaw expressed his pleasure at the progress achieved in the study of the relation of wind to the distribution of pressure. He called attention to the footnote on p. 29, "No account is taken of vertical velocity in this treatment since its inclusion makes the mathematics intractable." That was disturbing, because vertical motion was a characteristic feature of changing weather. He described the paper as "superficial," because the treatment was limited to a horizontal or isogeodynamic surface which excluded vertical motion. He suggested that an isentropic surface might be found more useful for the display of atmospheric motion than an isogeodynamic surface. No energy was required to maintain circulation along an isentropic surface. Even when the surface is vertical it indicates convective equilibrium, a "labile" state; moving air is equally at home in any part of it, and the same is true for any inclination of an isentropic surface. At the same time motion across the surface is not possible without previous gain or loss of heat. A series of isentropic surfaces is a guide to the motion of the atmosphere. He exhibited a map of normal isentropic and isothermal lines in a section of the atmosphere from pole to pole, combined in one diagram, based on the separate figures in Vol. II. of his " Manual of Meteorology "; he pointed out the characteristic features of parallelism of the two sets of lines in the regions of atmospheric disturbance and criss-crossness in the quiescent regions. He explained that a special advantage of setting out atmospheric conditions on an isentropic surface was that from the equation for change of entropy (expressed in terms of change of pressure and change of temperature) it must be inferred that on an isentropic surface a line along which pressure is uniform (an isobar) must also have the temperature uniform; consequently isobars are also isotherms and the representation is simplified thereby, though it may be somewhat complicated by kinks in the isentropic surface representing what are sometimes referred to as " discontinuities."

Note added 21st June, 1929.—The facility with which conditions can be explained by reference to isentropic surfaces may be illustrated by the following explanation of the diurnal variation of wind in steady weather. Imagine a flat land surface between two seas across which air is circulating with a moderate and uniform wind—the condition would not be satisfied either at mid-day or midnight but somewhere between the two. During the night the surface layers over the land lose their entropy, but those over the sea retain theirs, consequently during the night the isentropic surface on approaching the land has to mount and find its continuation somewhere aloft; it will descend again when the land is passed. Hence the surface of air-flow is no longer the surface of land. The land air is left imprisoned and stagnant between the upward flow on the windward side and the downward flow on the lee along the isentropic surface.

Dr. F. J. W. WHIPPLE expressed his admiration for the skilful way in which mathematical discussion and practical meteorology were blended in the *Memoir*. He thought that much could be learned with regard to changes in the geostrophic balance by the study of such phenomena as land and sea breezes. It was well known that the wind followed the sun. At a coast station, such as Aberdeen, the sea breeze set in nearly at right angles to the shore and presumably at right angles to the local isobars. In the course of a few hours the wind veered until it was nearly parallel to the shore. The off-shore wind at night behaved in the same way.[1]

Mr. C. S. DURST *(communicated)*: 1.—When a trough of low pressure with uniform isobars is moving across the surface of the earth, it is pointed out in the *Memoir* that there will be no general convergence of air at the trough line, as all the isallobars will be congregated along the actual line of trough (the type of barograph trace being one in which there is a marked V at the time of passage of the trough). The accompanying diagram shows schematically a section of the atmosphere through a cold front which is moving with velocity v at right angles to itself,

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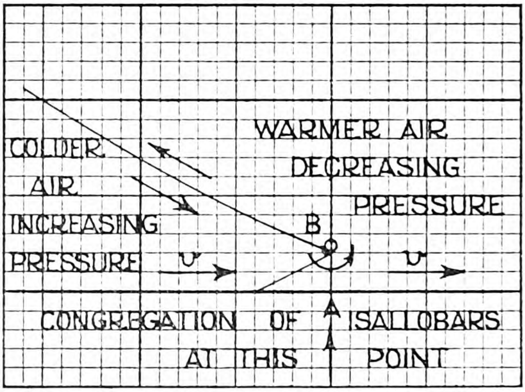
[1] Unfortunately the method of approximation adopted by the authors in solving the equations of motion cannot be used for this problem of land and sea breezes. The assumption which underlies the analysis in the *Memoir* is that the changes in the pressure gradient in 24 hours are but small.—F. J. W. W., Sept. 26th, 1929.


COLDER AIR INCREASING PRESSURE
WARMER AIR DECREASING PRESSURE
B
A
v
v
CONGREGATION OF ISALLOBARS AT THIS POINT

and from this diagram some conclusions may be drawn. At the point where the isallobars are congregated (point A on the diagram) there will be a strong tendency for wind to blow across the isallobars, which will account for the strong wind gusts which are found accompanying the passage of a cold front. There is then (considering only the wind component at right angles to the line of front), a sudden peak of wind velocity in an otherwise uniform field. When the equation of continuity is applied to such a distribution in two dimensions with vertical and horizontal axes at right angles to the line of the "front," it follows that there must be a violent up-rush of air before the line of front and a down-rush behind the "front." There appears to be a certain amount of evidence for the presence of this down-rush as well as the well known up-rush of air in fronts. In the case of an Imperial Airways machine piloted by Pilot G. P. Olley which crossed a line squall on December 31st, 1924, it is recorded[2] that after being lifted from a height of 400 feet to 2,800 feet in a minute and a half there was a huge downward bump. The airship R.34 on encountering a minor cold front over the North Sea experienced a downward bump after the upward bump. The presence of this wind due to the isallobaric gradient, together with the vertical velocities described, is sufficient to account for the motion of the air in the roll cloud at the point B in the diagram in which there is rotation as indicated by the arrow. There is no essential feature of difference between the structure of a front described here and that given by Giblett[3]; but by directly connecting up the vertical velocities with the characteristic of the barograph it may serve as a step forward in the classification of cold fronts with a view to forecasting, not only the approach of a front, but the type of front which may be expected.

2.—It is often seen that the last member of a family of depressions becomes a dying cyclonic whirl near the eastern edge of a polar outburst. In such a case the movement of the whirl is controlled by the isallobaric gradient, and its movement may be forecast on the rules given in this *Memoir*. The direction of movement in such a situation would also be given by the old empirical rule that a depression moves towards the isallobaric low, but it is very satisfactory that the empirical rule should be supported by the exposition of the physical reasoning underlying it.

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[2] *Meteor. Mag.*, February, 1925. A plunge through a line squall.

[3] *Journal of the Royal Aero. Soc.*, **31**, June, 1927, p. 509. M. A. Giblett. Line squalls.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

May 15, 1929.

At the *Ordinary Meeting* the following candidate was balloted for and elected a Fellow of the Society:—

THOMAS WILSON WORMELL, B.A., Solar Physics Observatory, Cambridge.

Mr. J. Edmund Clark gave an informal talk on the phenological effects of the winter of 1929 (See *Journal*, pp. 271-272).

June 12, 1929.

A special meeting of the Society was held on this date at the Rothamsted Experimental Station, Harpenden (See *Journal*, pp. 301-302).

June 19, 1929.

At the *Ordinary Meeting* the following candidate was balloted for and elected a Fellow of the Society:—

EMLYN LLEWELYN DAVIES, Experimental Station, Porton, Wilts.

CORRESPONDENCE AND NOTES

Weather Record attributed to Dr. Buxton.

In the library of the Royal Meteorological Society are two manuscript volumes, each of which contains observations made in Chichester and which clearly constitute the two halves of a single observer's record. The first volume covers the period October, 1769, to September, 1770, and the second carries the record on from October, 1770, to May, 1772.

It is very curious that these two volumes, undoubtedly parts of one and the same record, did not come into the Society's library at the same time, nor through the same channel. The second volume was the first to be presented. In March, 1885, a Mr. A. L. Lewis purchased it from a costermonger's barrow and wrote to Mr. G. M. Whipple, Superintendent of Kew Observatory, suggesting that the book was worthy of preservation and offering it to the Observatory library. Mr. Whipple, in reply, suggested that the library of the Royal Meteorological Society would be a better repository, and Mr. Lewis accordingly presented the volume to the Society. In doing so he attributed the diary to a Dr. Buxton, although it seems that he could only have done so by misunderstanding the inscription by the diarist on the second page of the volume:—" Of the Air and epidemic Diseases in ye City of Chichester and the adjacent Country, also An Account of the Air and epidemic Diseases communicated by Dr. Buxton at Chelmsford, Essex." The name Buxton only occurs in one other place in this volume; this is where the diarist describes his rainfall symbols, and adds:—" There is added an improvement of this character from Dr. Buxton. . . ."

Volume I. was not presented to the Society until 12 years later, when Mr. G. J. Symons gave it to the library in November, 1897. Thus, after the lapse of 125 years from the end of the record, the two volumes of this register came together once more. The name of Dr. Buxton was attached to this volume also, but whether it was so attributed by Mr. Symons, or whether it was merely because the common authorship of the two parts was at once recognised it is now impossible to say. It is possible that a note by the diarist, himself obviously a doctor, that "my father had observed ye autumnal fevers for about 50 years past" might have suggested to Symons that the Dr. Buxton so often mentioned in this volume was, in fact, the diarist's father. In any case, the proposed Dr. Buxton authorship seemed to rest on very slight foundation, if any at all.

An investigation into the history of Dr. Buxton, of Chelmsford, at once disposes of the possibility that the diarist was a son, or, indeed, any near relation of his. Dr. George Buxton, F.R.S., was born on the 14th of December, 1730. He could not, therefore, in 1769, have been observing "ye autumnal fevers" for 50 years. In any case, he had no children, and no other member of his family, a well-known one in Essex, is recorded as having adopted the medical profession. It is interesting to note that it has hitherto been unknown that any regular meteorological observations were made by this Dr. Buxton, and the extracts given by the diarist in this Chichester journal appear to be all that now survives of the Chelmsford record. It is clear that Buxton must have had a fairly good equipment of instruments.

There can be very little doubt that the diarist we are seeking is Dr. John Bayly, of Chichester. This physician was born in Chichester on 17th February, 1735, and was the son of Dr. George Bayly, of that city. He graduated M.D. from Edinburgh in 1757, his *dissertatio medica inauguralis* being "*De frigore quatenus morborum caussa.*" He then commenced practice in his native city and finally died there on the 11th of November, 1815. This gentleman fits all the slight evidences of identity contained in the record, and this authorship is confirmed by a very singular detail. The volumes contain a few sheets of loose paper, consisting mostly of the rough notes from which the fair copy of the observations in the books were written. One of these sheets, however, is a slip of paper dated 29th December, 1771, and in the handwriting of the diarist. It is a prescription intended for a patient suffering from a "remitting fever" and it is initialled "J. B."

Dr. John Bayly was evidently a practitioner of great skill and a man of remarkable personality. After his death a professional colleague in Chichester, Dr. Thomas Sanden, published, in 1816, a tract entitled "Tribute," in memory of the deceased physician. This tract would most likely shed some light on Dr. Bayly's meteorological activities, but it is now so scarce that it seems impossible to hear of a copy. It is not to be found in any of the great public or medical libraries, and there is no copy in the library of the Sussex Archæological Society.

The XVIIIth century is rich in the names of famous medical men who were assiduous meteorological observers. Huxham, Hillary, Wintringham, and "the indefatigable Dr. Short" are probably the most famous, but to the list we must now add the names of Buxton and Bayly as workers in the same field. Bayly's register contains many notes of a medical character such as might tend to throw light upon a connection between the state of the atmosphere and prevailing diseases, and there are frequent quotations from Huxham's well-known work, "*De aere et morbis epidemicis.*"

Great indebtedness must be acknowledged to a number of people who have provided information in this matter, and notably to W. J. Bishop, Esq., of the Royal College of Physicians, and Miss M. H. Cooper, of the Sussex Archæological Society. C. E. Britton.

A Contribution to the Climatology of Western China.

The amount of information available about the weather conditions of the far interior of China is not yet so great as one could wish, and the long record kept at the Friends Mission Hospital, T'ung Ch'uan, in the province of Szch'uan, Western China, in about 31°N., 105°W., is of great value. Observations of rainfall were commenced in May, 1905, and temperature and humidity were added in February, 1917. Regular manuscript returns were sent by Miss A. S. Marrs from 1920 until 1926, when the missionaries were obliged to leave the station owing to the disturbed state of the country. The mission station has recently been re-established, but it has not been found possible to resume the observations.

The observations were made on level meadow ground in the courtyard of the mission. The thermometer screen was about 20 feet to the east of an eight-foot wall, with two feet of open work above the masonry. The rain gauge was some 40 feet to the south of the screen, 19 feet to the east of this wall and the same distance to the west of a two-storey house; there were a few small trees, but none nearer than about 15 feet. The height of the station above mean sea level was about 1,100 feet. The thermometer screen was of the conventional shape and size, but the walls consisted only of single louvres until 1921, when a double-louvred screen was constructed in accordance with M.O. specifications. The thermometers had not been certified, but in 1921 a standard thermometer was sent out by the Royal Meteorological Society, and from a comparison with this the observer stated that in January, 1922, the dry bulb was about 0.5°F. too low and the wet bulb about 1°F. These corrections have not been applied in obtaining the values of humidity in Table III., which can therefore be regarded as only approximate. The comparison of the dry bulb readings with those of the minimum thermometer shows that the two sets are concordant, and probably neither thermometer was seriously in error.

The bottom of the 5in. rain gauge having decayed some time before 1921, the funnel was fitted into a glass bottle, and stood with the rim only 5 inches above the ground, so that the readings may not always be free from insplashing. Observations were made at 8h. local time, except in June, July and August, 1922, when they were at 7h. 30m., and from February to October, 1924, inclusive, when they were at 6h.

The mean temperature, represented by the mean of the mean daily maxima and mean daily minima, is given for each month in Table I. The comparatively low readings in 1917 are shown almost equally by the maximum and minimum thermometers, and are probably real.

The rainfall amounts are shown in Table II. It will be noticed that on two occasions (January, 1906, and February, 1924) no rain was recorded throughout a month, and on two other occasions (August, 1910, and July, 1921) the total exceeded 21 inches.

Table III. gives a summary of the observations in the usual form. The mean temperature is the mean of the mean daily maximum and mean daily minimum temperatures. The mean monthly maximum for each month is the average of the highest temperatures recorded in each month of that name from 1917 to 1926; the corresponding figure for the year is the average of the highest temperatures recorded in each of the years in question. The mean monthly minima were obtained in a similar way. It appears that, in spite of the low latitude and moderate elevation,

TABLE I.—MEAN TEMPERATURE IN °F. AT T'UNG CH'UAN, 31° N., 105° W.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1917	—	46.7	47.4	57.5	66.9	72.7	77.5	—	—	57.0	49.8	—	—
1918	38.1	44.1	52.7	60.4	72.1	71.4	76.9	75.9	67.8	63.5	50.1	43.0	59.7
1919	40.3	43.6	56.5	63.1	70.6	76.2	77.7	79.7	68.1	59.3	50.9	42.4	60.7
1920	42.1	40.9	47.7	59.0	68.5	74.9	76.4	—	70.5	61.9	54.5	43.4	—
1921	39.5	44.8	49.8	63.2	68.1	72.3	74.1	78.0	67.7	59.7	52.2	46.3	59.7
1922	41.4	46.7	54.1	63.9	72.2	77.7	79.1	80.8	71.2	64.7	52.1	44.9	62.5
1923	42.1	45.2	59.5	65.1	72.9	76.0	79.7	81.5	71.7	64.1	55.7	46.3	63.3
1924	43.3	45.7	53.8	—	68.9	72.7	77.9	79.1	71.2	61.1	—	—	—
1925	41.0	—	—	—	75.5	79.4	83.1	79.7	71.1	64.8	56.1	46.3	—
1926	43.9	45.9	52.8	64.1	—	—	—	—	72.3	62.7	52.4	45.5	—

TABLE II.—PRECIPITATION IN INCHES.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
1905	—	—	—	—	.25	5.44	5.24	—	7.78	1.31	1.09	.76	—
1906	.00	.46	.67	3.40	2.91	2.10	9.70	10.82	4.89	.97	.48	.41	36.81
1909	—	—	—	.78	2.15	9,43	8.34	8.74	6.95	1.55	.41	.27	—
1910	.22	—	.67	3.07	1.59	4.21	5.83	21.65	6.06	5.18	.61	.35	—
1911	.10	.80	.89	2.07	3.01	4.40	7.39	9.21	13.18	1.76	1.10	.44	44.35
1912	—	—	—	—	—	—	—	—	.89	1.03	.30	.29	—
1913	.40	.62	1.95	1.11	5.30	2.69	2.21	8.73	7.56	3.02	.07	.20	33.86
1914	.05	.73	1.91	2.15	.99	.79	14.44	9.94	1.59	2.45	1.51	.51	37.06
1915	.79	.24	.41	1.78	3.97	1.88	12.18	4.27	.79	2.84	.53	.02	29.70
1916	.29	.39	.93	4.80	4.31	5.27	3.93	4.62	4.98	5.52	.28	.25	35.57
1917	—	.42	1.41	1.86	2.52	8.52	6.89	—	—	3.08	.47	.29	—
1918	.33	.42	.89	1.21	2.74	6.29	4.62	5.14	2.75	1.48	1.00	.21	27.08
1919	.33	.20	.93	.47	3.63	4.24	8.01	6.24	5.08	2.69	.10	.31	32.23
1920	.07	.59	1.79	2.61	3.05	6.08	9.07	—	6.03	4.60	.65	.52	—
1921	.39	.30	.88	2.70	5.03	12.47	21.07	4.06	7.51	2.21	.95	.68	58.25
1922	.42	.35	1.64	2.37	—	6.13	13.89	7.85	5.47	1.07	.68	.03	—
1923	.31	.61	1.05	4.13	2.30	5.75	6.69	3.20	4.20	1.68	1.08	.14	31.14
1924	.30	.00	.40	—	2.24	2.50	2.81	2.99	.74	2.15	.30	.14	—
1925	.48	.71	.65	1.71	.73	11.16	6.70	8.74	5.89	1.89	.43	.20	39.29
1926	.26	.62	1.23	1.36	4.33	4.83	11.60	5.74	7.28	2.04	.94	.37	40.60

TABLE III.—METEOROLOGICAL TABLE FOR T'UNG CH'UAN.

Lat. 31°N., Long. 105°W., Height above M.S.L., 1,100 feet.

Month.	Temperature.							Relative Humidity.†	Cloud Amount. Scale 0-10.†	Precipitation.		Days of			
	Daily Mean.*	Mean Daily.		Mean Monthly.		Record.				Monthly.	Record in day.	Precipitation ‡	Snow.	Strong wind or gale.	Thunder.
		Max.	Min.	Max.	Min.	Max.	Min.								
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%		inch.	inch.				
January -	41.3	49.2	33.4	58	25	64	21	58	7.6	0.30	0.30	4	0.4	0	0
February -	44.7	52.7	36.6	64	27	72	24	61	7.8	0.47	0.33	5	0.2	0.1	0
March- -	52.9	62.0	43.7	76	34	90	27	73	6.3	1.08	1.10	7	0	0	0.2
April - -	62.1	71.8	52.5	85	45	91	39	84	7.2	2.21	1.50	10	0	0.4	0.7
May - -	70.4	80.2	60.6	91	53	98	46	87	7.4	2.84	2,50	11	0	0.4	1.4
June - -	74.7	83.9	65.5	95	59	99	54	82	7.1	5.48	5.15	13	0	0.2	1.0
July - -	78.1	87.0	69.3	96	62	98	51	93	6.7	8.45	4.60	13	0	0.1	1.9
August -	79.3	88.4	70.2	97	62	102	51	93	5.7	7.62	2.83	10	0	0.1	2.9
September -	70.2	77.6	62.8	91	55	95	48	95	7.6	5.24	2.78	14	0	0.2	0.1
October -	61.9	69.0	54.8	77	48	82	42	90	8.8	2.43	2.00	10	0	0.4	0.2
November -	52.8	60.9	44.7	72	34	78	27	79	7.7	0.65	0.61	6	0	0.3	0.1
December -	44.9	52.2	37,7	61	27	65	20	64	7.9	0.32	0.37	4	0.1	0.1	0
Year -	61.1	69.6	52.7	98	24	102	20	80	7.4	37.09	5.15	107	0.7	2.3	8.5
Years -	1917-1926								1921-1926	1905-1926	1917-1926				

* How obtained, ½ (Max. + Min.). † Mean of observations at 8h. ‡ 0.01 inch or more.

frosts are experienced every year in December, January and February, and occasionally in November and March.

Relative humidity and cloud amount are based on observations at 8h. local time. The high humidity from July to October and the great amount of cloud throughout the year are especially noticeable. Rainfall is not especially heavy, but in summer violent falls are experienced during thunderstorms. The record of phenomena are especially valuable. In addition to those given in the table, in the ten years 1917-1926 hail was recorded once in June, once in August and once in September, and fog once in June and once in October. Wind direction was not recorded until nearly the close of the record.

Although the greatest fall in a rainfall day is recorded as 5.15 inches in June, 1925, a much heavier fall occurred in June, 1921. A thunderstorm began about midnight on the 22nd-23rd, and became violent at 1.45 a.m. At 8 a.m., the usual morning hour of observation, the rain gauge gave a reading of 3.03 inches, and there was much flooding and damage to houses. Later in the morning a more violent thunderstorm began, and Miss Marrs read the gauge again at 1 p.m., the reading being 4.42 inches, a total of 7.45 inches in 12 or 13 hours. The city was badly flooded, some of the inhabitants being drowned and others rendered homeless. It was reported that two soldiers were struck by lightning and killed. The letter describing the occurrence ends:—

"The Chinese say they have not had such a storm for many years, and believe it is because a dragon has been stolen from one of the temples outside the West Gate."

Another serious flood was recorded on July 11th, 1921, following on the fall of more than eleven inches of rain in five days.

C. E. P. Brooks.

The Persistence of Types of Pressure Distribution over the British Isles in Winter.

In his "Aids to Forecasting"[1] E. Gold has put down the pressure type, chosen from 28 categories, prevailing over the British Isles at 0700 G.M.T. daily from January 1st, 1905, to December 31st, 1918.

The aim of this present note is to endeavour to determine from Gold's actual allocations what are the chances of any given pressure type persisting in winter for 3 or more days once it appears, defining winter as the months January, February, March, October, November and December, and a persistence for 3 days to mean that the same type was allocated for three consecutive days, including the day of its initial allocation, longer persistences being similarly defined.

The results obtained from the survey are set out in the table that follows. One or two points arise concerning the compilation of that table. On very many occasions Gold gave alternatives for the pressure type on a given day; in all such cases I have assigned full value to each of the alternatives given. Again, it needs to be noted that columns 2 and 3 of the table are mutually exclusive. Further, the calculation of the column headed "approximate chance of a group of 3 or more days following a first appearance of type" may need some explanation. That chance for any given type is obtained by adding together the entries in columns 2 and 3 for the type in question (thus arriving at the number of initial appearances of the type) and then dividing the entry in column 3 into the aggregate, expressing the result to the nearest whole number.

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[1] E. Gold, "Aids to Forecasting," *London Meteorological Office, Geophysical Memoirs* No. 16, 1920.

It further needs to be noted that in the table only 20 of Gold's 28 types are given. Of the remaining 8 types Ia, IX, IXa and XV had only one group of three or more consecutive occurrences each, though it must be stated that types IX and IXa did not occur with any great frequency; the other four types had no group at all of 3 or more, type XIIIa occurring but very seldom indeed.

For full details of the pressure distributions connoted by the various Gold types, the reader is referred to the original publication.[1]

There was no case of any type persisting longer than 8 days.

Gold type.	No. of isolated occurrences or groups of two days and no more.	No. of groups of three or more days.	No. of occasions of groups of—					Approximate chance of a group of 3 or more days following a first appearance of type 2.
			3 days.	4 days.	5 days.	6 days.	7 or 8 days.	
I.	169	25	19	6	0	0	0	1 in 8
II .	157	18	12	3	2	1	0	,, 10
III.	124	3	2	1	0	0	0	,, 42
IV.	154	2	1	0	1	0	0	,, 78
V.	132	5	1	2	1	1	0	,, 27
Va.	143	14	9	2	2	1	0	,, 11
VI.	70	7	3	2	1	0	1	,, 11
VIa.	95	7	4	2	1	0	0	,, 14
VII.	116	8	7	1	0	0	0	,, 15
VIIa.	70	2	2	0	0	0	0	,, 36
VIIb.	58	9	4	1	2	2	0	,, 7
VIIc.	63	9	7	1	0	1	0	,, 8
VIII.	25	2	1	0	1	0	0	,, 14
VIIIa.	21	4	4	0	0	0	0	,, 6
VIIIb.	59	5	3	2	0	0	0	,, 13
X.	79	3	1	2	0	0	0	,, 27
XI.	56	3	2	1	0	0	0	,, 20
XIa.	88	2	2	0	0	0	0	,, 45
XII.	86	2	2	0	0	0	0	,, 44
XIV.	76	3	2	0	1	0	0	,, 26

Considering the table it will be seen that types VIIIa (anticyclone off north Scotland and low pressure over Spain), VIIb (anticyclone over Scandinavia and depression west of the Bay of Biscay), VIIc (high pressure centred over Scandinavia and the northern Baltic, low pressure over Spain and west Iceland), and I (high pressure over Bay of Biscay and low over Scandinavia), show most likelihood of persistences for 3 or more days with types II, Va and VI not far behind. The chances of persistence with types IV, XIa, XII and III may be regarded as very small.

It is hoped that the results obtained may not be without some value in forecasting for more than 48 hours ahead.

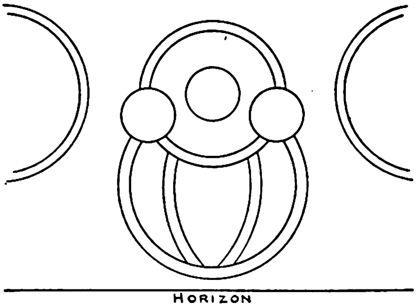
I hope to be able to continue similar statistics for persistences in "summer" when time and opportunity permit of my embarking upon the somewhat laborious work involved.

William H. Pick.

13th July, 1929.

An Early Illustration of a Halo Complex.

The earliest halo observation of note is generally taken to be that described and figured by Scheiner at Rome in 1630. However, De Bry[1] gives an illustration of a halo complex observed during the voyage of Heemskerk and Rijp to Spitsbergen in 1596. This illustration, "A Wonder in the Heavens and how we caught a Bear," is reproduced by Sir Clements R. Markham[2] in his book on polar exploration, but he makes no comment thereon. This being so it might be well to call the attention of meteorologists to this complex, which presents some peculiar features. The halo surrounding the sun is probably that of 22° with its parhelia, while the arcs on either side might well be one or other of the lateral arcs of the halo of 46°. The portion of the halo figured below the sun is rather more difficult to identify. If it were figured above it might be the combination of the parhelic circle and the arcs of the anthelion somewhat similar to the halo described in the *Quarterly Journal* for January, 1927.[3] However, the drawing is rather confused, and no doubt the perspective and scale are rather bad, and, as the title indicates, the halo forms the background to a spirited rendering of a bear hunt at sea. A quaint touch (not reproduced in the diagram) is that the sun and parhelia are drawn with features and rays just like the sun on insurance plates.



CICELY M. BOTLEY.

Useful Solar and Meteorological Data, 1927 and 1928.

The following tables, the publication of which was begun in the *Journal* for October, 1925, and continued in July, 1926 and 1928, contain a number of data of interest in connection with the meteorology of the globe, but which are not readily accessible to most investigators. They are here brought up to date as far as possible. The magnetic character figures have been extracted from the *Caractère Magnétique* published by the Royal Meteorological Institute of the Netherlands. The sunspot figures are extracted from *Astronomische Mitteilungen;* a relative number of 100 corresponds with about one five-hundredth of the sun's visible disc covered by spots, including both umbra and penumbra. The other data are compiled from publications and manuscripts in the possession of the Meteorological Office.

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[1] De Bry India Orientalis 1599.
[2] Sir C. R. Markham, "The Lands of Silence," Cambridge 1921.
[3] F. J. W. Whipple, *Q.J.R. Meteor. Soc.*, **53**, 1927, pp. 80-2.

DAILY RELATIVE SUNSPOT NUMBERS, 1927.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	67	122	41	77	48	32	98	49	61	43	65	35
2	67	136	46	81	53	42	120	59	61	32	56	26
3	65	157	46	89	68	41	101	35	52	51	32	30
4	81	155	67	77	73	42	111	50	37	65	25	17
5	89	173	59	102	99	51	97	51	50	82	45	34
6	76	119	58	98	105	63	72	48	44	82	36	64
7	111	163	71	98	97	79	61	37	47	85	33	58
8	105	116	88	80	78	79	45	17	40	90	15	72
9	123	127	91	136	91	57	54	18	44	95	46	88
10	116	124	46	101	110	54	52	19	47	115	71	85
11	124	106	55	163	101	63	42	32	68	112	91	85
12	79	82	50	137	143	72	16	31	92	74	101	53
13	53	58	74	125	97	73	14	53	96	90	113	62
14	70	98	70	138	57	54	32	59	103	79	100	47
15	68	71	105	131	59	32	32	70	154	76	91	20
16	76	58	95	157	67	22	44	68	126	54	84	19
17	88	79	125	124	86	51	47	80	111	44	87	17
18	111	76	126	120	98	37	45	97	85	32	81	10
19	89	65	147	91	67	35	22	79	81	53	64	8
20	76	67	114	66	72	26	34	58	81	40	79	11
21	70	46	131	59	81	32	43	49	55	66	78	17
22	80	52	121	68	87	43	49	61	44	66	70	14
23	65	53	82	62	88	45	49	68	73	56	81	32
24	85	45	56	49	101	64	52	68	86	65	88	59
25	44	54	49	51	90	73	68	56	85	69	87	63
26	42	59	23	90	86	88	68	56	58	46	70	33
27	38	79	38	93	88	80	75	58	77	25	67	56
28	49	64	16	40	43	116	34	52	38	25	45	64
29	64	—	31	55	58	114	44	68	27	29	59	70
30	109	—	16	48	34	113	39	66	30	40	57	73
31	149	—	21	—	28	—	43	56	—	75	—	79

DAILY RELATIVE SUNSPOT NUMBERS, 1928.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	91	89	86	96	128	124	124	102	61	68	53	46
2	100	50	65	95	143	130	130	116	49	68	47	55
3	75	65	49	80	125	113	128	116	85	62	49	64
4	81	41	49	108	111	111	85	107	69	47	48	95
5	90	46	61	118	118	94	56	80	64	45	60	112
6	105	34	73	145	118	98	50	64	49	26	70	95
7	85	35	93	118	136	104	60	71	57	64	66	94
8	95	33	94	143	135	76	93	59	103	58	53	85
9	95	24	124	130	134	43	87	75	101	53	81	68
10	81	31	83	112	117	30	82	80	89	71	89	83
11	75	29	105	118	85	26	66	73	81	92	75	76
12	79	39	102	106	75	16	122	74	89	74	84	101
13	50	31	90	97	53	31	127	92	75	86	90	90
14	61	29	92	96	26	34	121	92	56	83	73	95
15	63	74	108	90	17	34	137	70	59	83	77	101
16	83	73	117	87	16	52	127	77	46	84	61	89
17	76	75	118	63	15	67	141	58	51	77	49	56
18	63	69	125	27	14	71	117	47	71	82	52	46
19	72	104	141	42	15	95	126	53	83	70	58	20
20	53	131	101	35	4	86	137	59	102	67	58	28
21	67	113	83	31	15	94	127	71	111	75	37	25
22	45	128	92	22	23	95	105	83	106	53	28	18
23	64	127	66	26	40	129	71	102	108	73	33	20
24	104	112	76	28	36	149	60	92	133	79	16	14
25	116	109	72	43	49	163	58	104	141	53	7	8
26	136	119	50	53	40	131	65	114	170	45	29	12
27	135	123	70	51	53	137	63	113	145	29	23	27
28	96	104	61	77	102	158	67	105	115	27	28	32
29	91	95	75	76	131	131	95	84	110	23	8	50
30	70	—	62	104	158	121	102	84	113	37	28	57
31	92	—	66	—	154	—	110	82	—	50	—	68

DAILY VALUES OF THE MAGNETIC CHARACTER, 1927.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	**1.3**	0.4	1.2	0.5	0.4	0.9	**1.0**	0.7	1.2	*0.3*	0.0	0.8
2	0.7	0.2	*0.3*	0.5	0.5	**1.0**	0.6	1.0	0.5	0.9	*0.0*	0.9
3	0.1	0.9	0.4	0.3	**1.3**	0.6	*0.1*	0.9	0.6	0.8	0.1	0.2
4	**1.5**	0.4	0.2	1.0	1.0	0.3	0.2	0.8	**1.4**	*0.1*	0.5	*0.0*
5	1.0	0.4	0.5	0.7	**1.8**	**1.1**	0.6	0.8	0.9	0.9	0.2	0.9
6	0.8	*0.0*	0.6	0.2	0.6	0.6	0.7	*0.1*	**1.2**	1.0	0.1	1.0
7	**1.9**	*0.0*	0.5	0.9	**1.6**	0.3	**1.0**	*0.2*	**1.2**	1.5	*0.0*	0.7
8	1.1	0.8	0.7	0.9	1.0	*0.0*	0.9	0.3	1.2	1.3	0.6	0.7
9	*0.1*	**1.5**	**1.4**	**1.4**	0.9	0.1	0.1	0.2	**1.4**	1.0	0.4	0.7
10	*0.1*	**1.2**	1.3	0.8	0.3	0.7	*0.0*	0.2	**1.6**	**1.8**	0.2	0.6
11	0.8	0.5	0.8	**1.5**	*0.0*	**1.0**	0.2	0.3	1.0	0.9	0.2	0.1
12	0.8	1.0	0.5	**1.0**	*0.0*	**1.0**	0.2	0.2	0.5	**2.0**	0.2	0.3
13	0.5	1.1	0.8	0.9	0.3	0.3	0.3	*0.0*	0.9	**1.7**	0.5	**1.7**
14	0.7	0.6	0.8	**1.9**	0.5	0.5	0.2	0.4	1.0	0.7	*0.0*	**1.4**
15	0.3	0.4	1.1	0.9	1.2	0.6	*0.1*	0.8	0.8	0.4	0.0	1.2
16	0.2	1.1	**1.8**	0.1	0.9	0.2	*0.1*	0.7	*0.2*	0.3	0.4	0.7
17	0.6	0.7	**1.6**	*0.0*	*0.1*	0.6	0.9	0.2	*0.2*	*0.1*	0.2	**1.3**
18	0.6	0.9	1.1	*0.1*	*0.1*	0.1	0.2	0.2	0.2	0.3	**1.5**	**1.2**
19	0.8	0.7	0.9	0.1	1.0	*0.0*	0.7	**0.9**	0.2	0.5	**0.8**	1.1
20	0.1	0.4	1.0	*0.1*	**1.4**	*0.0*	0.7	**2.0**	0.7	0.5	0.7	*0.0*
21	*0.0*	*0.1*	0.2	*0.0*	0.6	*0.1*	**1.6**	**2.0**	0.4	*0.1*	**0.8**	*0.0*
22	*0.0*	*0.0*	*0.1*	*0.0*	0.4	0.3	**2.0**	0.8	*0.1*	**2.0**	*0.1*	0.1
23	*0.1*	*0.0*	*0.1*	0.9	0.3	0.2	**1.1**	0.5	*0.0*	**1.9**	0.0	0.5
24	**1.1**	**1.4**	*0.0*	**1.2**	0.2	*0.0*	0.8	0.2	*0.1*	1.0	0.4	*0.1*
25	**1.1**	**1.1**	*0.1*	0.9	0.3	0.1	0.4	*0.0*	1.0	0.8	*0.0*	0.1
26	1.1	1.0	1.3	0.2	*0.1*	**1.3**	0.7	*0.0*	1.0	0.9	0.3	0.3
27	0.3	0.6	**1.7**	0.1	1.0	0.7	0.8	0.3	0.8	0.3	0.5	*0.1*
28	0.2	**1.1**	**1.6**	0.0	**1.2**	0.3	0.2	0.2	0.7	0.3	0.1	**1.3**
29	0.6	—	0.9	0.3	0.4	0.3	*0.1*	**1.5**	1.0	0.7	**0.8**	0.5
30	0.3	—	0.8	0.5	0.2	0.7	0.3	**1.5**	0.9	0.8	**0.9**	0.1
31	0.1	—	0.6	—	0.2	—	0.3	0.9	—	*0.1*	—	0.8

NOTE.—The selected calm days in each month are printed in italics and the disturbed days in heavy type.

DAILY VALUES OF THE MAGNETIC CHARACTER, 1928.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	**1.1**	0.7	0.1	**1.0**	*0.1*	0.9	0.4	0.7	0.4	0.5	0.6	**0.9**
2	0.2	0.8	*0.0*	0.7	*0.0*	0.8	**1.3**	0.4	0.8	**1.2**	**1.3**	0.4
3	0.1	0.8	0.1	0.9	*0.0*	0.7	0.9	0.3	**1.5**	0.8	**1.7**	0,2
4	0.6	0.7	*0.0*	0 8	0.3	0.8	0.8	**1.1**	0.4	0.4	1.1	*0.1*
5	0.3	0.4	*0.0*	0.6	1.2	1.1	0.7	**1.7**	0.7	1.0	0.1	**1.2**
6	0.3	0.4	0.1	0.8	0.5	0.8	0.7	1.1	0.5	0.8	0.5	**1.5**
7	0.4	0.5	0.3	**1.3**	0.6	**1.1**	**1.5**	**1.1**	**1.6**	0.8	0.4	0.8
8	0.2	*0.1*	0.1	0.9	0.9	1.0	2.0	0.3	**1.5**	0.5	*0.0*	0.5
9	0.4	*0.1*	*0.0*	0,7	0.3	0.7	**1.2**	0.2	1.1	*0.0*	*0.0*	0.3
10	0.2	*0.2*	0.5	**1.0**	**1.4**	*0.0*	1.0	*0.1*	0.8	*0.4*	1.2	0.4
11	*0.0*	*0.0*	**1.8**	0.1	1.3	*0.1*	0.9	0.4	0.7	*0.4*	1.2	0.9
12	*0.0*	0.9	**1.3**	*0.1*	**1.4**	**1.2**	0.6	1.1	*0.3*	0.5	0.9	**1.1**
13	*0.1*	**1.0**	**1.3**	*0.1*	1.1	**1.3**	*0.1*	0.6	0.7	0.9	**1.6**	**0.9**
14	*0.0*	0.8	**1.2**	0.1	0.9	1.1	0.3	*0.1*	0.9	0.8	0.6	0.7
15	0.3	0.7	0.7	0.7	1.0	0.6	*0.1*	*0.1*	0.4	0.7	**1.3**	0.4
16	0.2	0.7	0.7	0.9	1.1	*0.3*	*0.2*	0.3	*0.0*	1.0	1.2	0.3
17	0.1	0.2	0.6	0.7	0.9	*0.3*	*0.2*	0.3	*0.1*	0.8	**1.3**	*0.0*
18	0.5	**0.9**	0.3	0.1	1.0	0.3	0.7	0.5	**1.5**	2.0	0.8	0.3
19	0.4	**0.9**	0.4	0.6	0.8	0.3	0.4	0.2	1.4	**1.2**	0,7	*0.0*
20	0.8	0.9	0.3	**0.9**	0.4	0.8	*0.2*	*0.1*	0.6	0.8	0.2	*0.1*
21	0.5	**1.1**	0.5	**1.0**	0.2	0.6	1.0	0.1	*0.2*	0.9	0.1	0.8
22	0.4	0.5	0.6	0.5	*0.1*	**1.7**	**1.3**	*0.0*	0.9	**1.1**	*0.0*	0.7
23	**0.8**	0.7	**0.9**	0.5	0.2	**1.2**	0.6	0.8	0.8	*0.4*	0.2	*0.1*
24	0.5	*0.0*	0.8	0.1	0.3	0.9	0.7	0.5	1.1	**1.7**	0.8	0.7
25	0.6	0.9	0.8	*0.1*	0.3	0.7	0.5	0.5	**1.6**	**1.8**	0.6	0.8
26	0.5	**1.0**	0.5	0.2	*0.1*	0.4	0.7	**1.7**	0.8	1.1	0.3	0.9
27	**1.6**	0.8	0.1	0.2	**1.7**	*0.3*	0.6	**1.6**	0.6	1.0	0.4	0.3
28	**1.1**	0.7	0.3	*0.0*	**1.9**	0.6	0.9	0.9	*0.1*	*0.3*	*0.0*	0.2
29	**0.9**	0.3	0.2	*0.0*	**1.7**	0.5	0.4	0.3	0.2	0.7	*0.0*	0.6
30	0.7	—	0.4	0.1	0.9	0.4	0.2	0.0	0.6	0.8	0.4	0.4
31	*0.1*	—	*0.1*	—	0.8	—	**1.1**	0.4	—	0.6	—	0.2

NOTE.—The selected calm days in each month are printed in italics and the disturbed days in heavy type.

MONTHLY MEANS, 1927 AND 1928.

		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
THE SOLAR CONSTANT* (in gram-calories per cm² per min.).	1927													
,, ,, ...	1928													
MAGNETIC CHARACTER	1927	0.62	0.66	0.80	0.60	0.65	0.47	0.56	0.61	0.77	0.84	0.35	0.63	...
,, ,, ...	1928	0.44	0.62	0.48	0.52	0.75	0.72	0.72	0.56	0.75	0.83	0.65	0.54	...
SUNSPOTS (Relative Number)	1927	81.6	93.0	69.6	93.5	79.1	59.1	54.9	53.8	68.4	63.1	67.2	45.2	...
,, ,, ...	1928	83.5	73.5	85.4	80.6	76.9	91.4	98.0	83.8	89.7	61.4	50.3	59.0	...
ICE-COVERED AREA (deviation from normal. Unit 1,000 sq. miles).														
Kara Sea	1927	...	...	...	0	0	+1	+6	−26	...	...	...	...	...
,, ...	1928	...	...	...	0	0	+1	−2	−37	...	...	...	...	...
Barents Sea	1927	...	...	...	+9	+54	+51	+54	−9	...	...	...	...	...
,, ...	1928	...	...	...	−5	−55	−156	−39	−29	...	...	...	...	...
Greenland Sea	1927	...	...	...	−64	−77	−46	−16	−2	...	...	...	...	...
,, ...	1928	...	...	...	−3	−20	+6	−9	−7	...	...	...	...	...
NEWFOUNDLAND BANKS (Deviation of No. of Icebergs from normal)	1927	+1	0	−10	+10	+23	+27	−20	−10	−9	−4	−3	−2	+3
,, ...	1928	−3	−10	−22	+73	+60	+19	+30	−8	−9	0	+1	−2	+129
ICELAND, NO. OF DAYS WITH ICE VISIBLE (Deviation from normal)	1927	−4	−4	−8	−7	−7	−7	−4	−2	0	0	0	0	−43
,, ...	1928	−4	−4	−8	−7	+7	−6	−4	−2	0	0	0	0	−28
TEMPERATURE AT EQUATORIAL STATIONS (Deviation from normal) °F.														
Ocean Island	1927	+1.1	+2.5	+2.8	+2.6	+2.7	+2.2	+1.6	+2.5	+3.4	+3.1	+2.7	+1.3	+2.3
,, ...	1928	−0.4	+1.5	+2.8	+2.1	+1.7	+1.6	+2.4	+2.4	+2.3	+3.7	+3.3	+3.3	+2.2
Colon, Panama	1927	+1.0	+0.4	+2.3	+1.5	+0.3	+1.3	+0.7	+1.4	+0.9	+1.8	+0.5	+1.3	+1.1
,, ...	1928	+1.5	+2.4	+1.7	+2.8	+1.9	+0.7	+2.1	+0.4	+1.7	+1.2	+0.3	+0.7	+1.4
Sierra Leone (Freetown)	1927	−1.2	−0.4	−0.4	−0.8	−0.3	−1.0	−0.7	−0.8	−0.8	−0.8	−1.1	+0.5	−0.6
,, ...	1928	−1.2	−1.8	−0.3	−0.7	−1.0	−1.2	−1.2	−2.2	−1.4	−2.2	−1.4	−1.1	−1.3
Entebbe	1927	−1.2	−0.6	−0.3	+0.4	+0.6	+0.3	+0.4	+0.9	+0.1	+2.8	+1.6	+1.2	+0.5
,, ...	1928	+1.7	+1.8	+1.0	−0.4	−0.4	−0.3	+0.6	+0.3	+0.8	+0.4	+0.8	+0.5	+0.6
Colombo	1927	+0.3	+0.4	−0.4	−0.4	−0.4	−0.3	+0.1	+0.8	0.0	+0.4	+0.4	+1.2	+0.2
,, ...	1928	+0.8	−0.4	+0.4	−0.2	+0.8	+0.8	+0.9	+1.0	+2.3	+0.4	+0.8	+0.8	+0.7
*Batavia														
,, ...														
VELOCITY OF SE. TRADE WIND AT ST. HELENA (Deviation from normal mi/hr.) ...	1927	−0.2	+0.4	−0.4	−2.0	+0.4	−3.8	−0.4	−1.6	−2.2	+2.7	+0.9	−0.4	−0.7
,, ...	1928	+0.4	−0.9	+0.4	+1.8	+0.4	−0.9	−1.8	−2.2	−1.1	+0.7	...	...	...

* Data not available

OBITUARY

SIR ARCHIBALD BUCHAN-HEPBURN.

The death occurred on May 17, 1929, at the age of 77, of Sir Archibald Buchan-Hepburn, of Smeaton-Hepburn, Co. Haddington, East Lothian, Archibald Buchan-Hepburn was the second son of the third Baronet. Educated at Glenalmond and Trinity College, Cambridge, he was called to the Bar in 1877, and he joined the south-eastern Circuit. In 1883 he succeeded his father, his elder brother having been killed in Mexico. He was Deputy Lieutenant for Co. Haddington, and was a Justice of the Peace.

Sir Archibald was elected a Fellow of the Scottish Society in 1895; he served several years on the Council and was Vice-President from 1908-10.

MR. HENRY JONAS.

We regret to announce the death on April 25, 1929, at Whyteleafe, Surrey, of Henry Jonas, at the age of 87. Henry Jonas was the senior partner of the firm of Messrs. Drivers, Jonas and Co., surveyors. He joined the firm when he was 17 years old, and was taken into partnership more than fifty years ago. He specialised in the management of country estates and in timber valuations.

Mr. Jonas was a Fellow of the Surveyors' Institution, and he was the Senior Member of the Surveyors' Association. He was a Life Fellow of this Society, and was elected in 1880.

MR. H. M. H. NEWBY.

It is with regret that we learn of the death on June 15, 1929, at Hove of Mr. H. M. H. Newby. Henry Marius Holmes Newby was the son of the late Rev. Henry Newby, Vicar of Mears Ashby, Northamptonshire. Mr. Newby led a quiet, retired life, necessitated by his physical disabilities; nevertheless, he had a great many interests, and chief among these were engineering, meteorology, and photography. His fine upright character and unselfish disposition endeared him to all who knew him.

He was elected a Fellow of this Society in 1902.

LORD ROSEBERY.

On May 21, 1929, the Earl of Rosebery died at his home, The Durdans, Epsom, two weeks after his 82nd birthday. The son of Lord Archibald Dalmeny, Archibald Philip Primrose succeeded his grandfather in 1868, and became the 5th Earl of Rosebery. He was educated at Eton and Oxford, and he subsequently had one of the most remarkable careers of his time, achieving fame in several different walks of life. He held many high offices, including those of Lord Privy Seal, Foreign Secretary and Prime Minister. He was famous as an orator, a writer on historical and literary subjects, and also as a sportsman. He was a Fellow of the Royal Society.

Lord Rosebery's Scottish home was at Dalmeny Park, near Edinburgh, and he often took an active part in the affairs of that city; he was Rector of the University in 1882-3. He was a Life Fellow of the Scottish Meteorological Society, and was elected in 1888.

We have also to announce the deaths of Mr. James Campbell Carson, of Belfast, elected May 19, 1909, who died on May 13, 1929; and Mr. Alexander Fowler Roberts, of Fairnilee, Selkirks, a Scottish Life Fellow elected in 1910, who died May 13, 1929, aged 85 years.

REVIEWS

Weather: Practical, Dramatic and Spectacular Facts about a little studied Subject. By E. E. Free and Travis Hoke. London (Constable & Co., Ltd.), 1929. 8°. Pps. 11+337, illus. 14s. net.

There can be no subject of more general interest than the weather, yet, except for a casual glance at the weather maps which appear daily in the newspapers, the man in the street makes little or no attempt to read anything about it. The reason for this apparent indifference is not far to seek. The man in the street requires simple explanations of meteorological facts familiar to him in everyday life; books of an elementary or popular kind do not give these in sufficient detail, while he is not attracted to the more advanced text books which might lead him too far out of his depth. He need have no fear of either of these in *Weather*. He will find collected there a mass of information with graphic explanations of meteorological facts and theories cleverly illustrated by analogies in which the proverbial steam kettle often figures.

In the preface the authors say " the book was planned not logically but psychologically " (a happy notion!). All their acquaintances were asked what they felt most need of knowing about the weather, and the replies to their queries are to be found in the pages of this volume. Messrs. Free and Hoke have succeeded in filling 300 pages with interesting matter, written in an original and attractive style. In dealing with so many aspects of the weather and subjects associated with it the authors have not been able to avoid slipping into some pitfalls in spite of their obviously wide reading. Who could agree with the authors that once upon a time " there was no weather," or that " all weather is owing to the existence of mountains "?

Reference is made to the old, old story, " The weather isn't what it used to be." Indeed, it is a matter for congratulation that it is not, if we are to believe the statement quoted regarding the summer of 1260: " The thunderstorms were so continuous that no-one dared leave the house, and the hailstones were as thick as three fingers and sometimes as thick as 15 fingers."

Spectacular facts, which serve to keep the reader's interest from flagging, are prominent throughout the book. Who besides the expert knows that 1,800 thunderstorms scattered over the world are in progress at any instant, or, as the authors put it, " Somewhere in the world nearly 2,000 separate thunderstorms are going all the time, and that average number will never decrease day or night or year after year," or that a cyclone may expend enough power in one day to run all the dynamos, motors, and steam engines in the world for 3 or 4 years! Some interesting information is also given about the severe storms known as tornadoes. The authors state that " a tornado in 5 minutes has been known to kill 250 people and to destroy 15,000,000 dollars' worth of property." They point out that " the worst destructive tornado in American history was that which swept over an unusally long path across Missouri, Illinois and Indiana on March 25th, and killed 695 people and injured 2,037, and destroyed 16,500,000 dollars' worth of property." What we miss in this good old England of ours!

The book is illustrated with excellent photographs and some cleverly designed diagrams, which are frequently of a distinctly numorous nature. Although *Weather* is not a book for serious study the authors are to be congratulated in producing a volume both informativè and amusing, which, while presenting to the reader a serious subject in a light and sometimes flippant way, will possibly stir up interest in a much neglected science. But a word of warning is necessary to those who may be induced through the pages of this book to make a closer study of meteorology: they will find that the explanations of meteorological phenomena given by Messrs. Free and Hoke are not always accurate, and differ materially from those given by experienced meteorologists.

L. G. G.

The Geography of the Polar Regions. Consisting of a general characterization of Polar nature by OTTO NORDENSKJÖLD and a regional geography of the Arctic and the Antarctic by LUDWIG MECKING. *American Geographical Society Special Publication* No. 8. Edited by W. L. G. JOERG. New York, 1928. Pp. vi. + 359. Illustrated. $4.

The American Geographical Society is to be congratulated on this excellently produced volume, in which is assembled the most recent information as to the geography and geology, physical features, climate and life of the Arctic and Antarctic. The work is more than a collection of facts; it is also eminently readable, and the numerous maps and photographs—there are no fewer than 108 illustrations—add greatly to the interest.

Dr. Nordenskjöld's contribution will probably appeal more to the general reader, both by the broader nature of the treatment and because the author's long personal experience of the Polar regions gives a stronger force to his narration. In 1901-1903 he was the leader of the Swedish Antarctic Expedition, and he has twice visited Greenland, so that he knows the great ice masses of both hemispheres. He regards the climate as the dominant feature of the Polar regions, and temperature as the major climatic factor, hence the greater part of his opening chapter on "The Climate of the Polar Regions" is occupied with a description of the conditions of temperature. The next most important factor, especially in the Antarctic, is the wind; precipitation is almost everywhere slight

There is a remarkable difference between the Arctic and Antarctic regions in respect of temperature. The Arctic is no uniform area of cold; the thermal conditions are exceedingly complex, especially in the brief but important summer season. Perhaps the strangest climate to find north of the Arctic circle is that between the coast and the inland ice in West Greenland. "The whole area has the aspect of a dry steppe region of a peculiar type: there are salt lakes and saline efflorescences, lakes with no outlet, peculiar phenomena of weathering, loess, and wind-blown sand." In this region the winter snowfall must be exceedingly small, while the summer temperature approaches that of central Sweden.

The Antarctic climate is of an entirely new type; it is neither continental nor maritime, but *glacial.* At sea level on the edge of the ice the summer temperature fails to reach 32°F., and is lower than on any known Arctic coast. In almost dramatic style the cause of these low temperatures is brought out; it is the strong wind blowing steadily off the inland ice. "It is not the normal temperature of the region that appears in our tables, but the cold brought from the interior of the continent."

The second chapter describes and classifies the ice forms. In this connection it is admitted that there is no evident reason why Greenland, which has comparatively mild summers, especially in the south and west, should carry such an enormous ice sheet; the explanation given is that the Greenland ice is a relic of the last Ice Age, when under more suitable conditions it spread down from the north. The ice sheet forms its own climate, and is thus able to maintain itself, though if it once disappeared probably it could not form again. The reverse problem is equally difficult, namely, to explain the presence of large ice-free areas in high latitudes where the conditions seem eminently suited for glaciation.

These questions lead to the third chapter, the causes and natural conditions of the Ice Age. The author emphasises the unity and world-wide nature of the catastrophe, which he thinks can only be attributed to a general lowering of temperature. He apparently regards the Ice

Age, in the more central parts of the ice-covered regions, as a single event; he rightly points out that too great importance may easily be attached to great weathering of old glacial deposits, as observations in the marginal belt of Greenland have shown that weathering in such a situation may proceed very rapidly. One cannot help feeling, however, that he dismisses too casually the really strong evidence for at least one interglacial period in Scandinavia itself.

Passing over the chapters on land forms and life, we come in Chapter VI. to an interesting discussion on the delimitation of the polar regions. Supan's limit of a temperature of 50°F. in the warmest month, which is generally adopted, serves for continental areas, but in some islands it leads to obvious absurdities. For example, the luxuriant forests of Tierra del Fuego, which are inhabitated by humming birds and parrots and where the people wear little clothing, fall within the polar regions! It seems logical in determining the limit to give winter temperatures some weight, though not so much as summer temperatures, and the author quotes with approval studies by Martin Vahl which give to the temperature of the coldest month one-thirtieth of the weight of the warmest month. But even this modification leaves the obviously temperate Staten Island within the polar regions, and the author regards as more acceptable a formula which places the boundary where $v = 9°\text{C.} - 0.1k$, v and k being the mean temperatures in °C. of the warmest and coldest months. It follows that if $v + 0.1k$ is less than 9°C. the region is polar; if greater than 9°C. the region is not polar. The use of this formula increases the width of the temperate belt in oceanic regions and narrows it over the continents. For example, if the January temperature is −40°C., the July temperature must reach 13°C. for the region to be regarded as temperate, but if the January temperature is 5°C., the July temperature need only rise to 8.5°C. The limits of the polar regions according to this formula are shown in two charts, which accord with one's expectations, and appear as a definite improvement on Supan's limit. The remainder of this chapter is concerned with the geographical sub-divisions of the polar regions, and forms an excellent introduction to the second part of the work. Dr. Nordenskjöld's concluding words will be echoed by all meteorologists, "special efforts should be made to secure long-period observational records of all kinds."

The Regional Geography by Dr. Mecking, which occupies over three quarters of the volume, is more the text book, but the text book of a specialist, very much up-to-date, systematic and complete; it is also of high literary standard. The sections on climate are short, but graphic; for example, the annual variation of temperature in the Arctic is summed up in a few words: "Hence autumn is a quiet dying away of nature, spring a sudden awakening." In general the presentation is both more complete and more orthodox than Dr. Nordenskjöld's, and the two sections of the book thus complement each other. For example, Nordenskjöld's bibliography is sketchy, but Mecking's occupies no fewer than thirteen pages, classified geographically.

The first part of the book has been translated from the Swedish by Dr. Ernst Antevs, the second from the German by the Editor. Both translations appear to be flawless, and the description of the Arctic night on p. 115, quoted from Dr. Nansen, rises to the level of true poetry: "Here and there are left a few waving streamers of light, vague as a foreboding—they are the dust from the aurora's cloak."

C. E. P. B.

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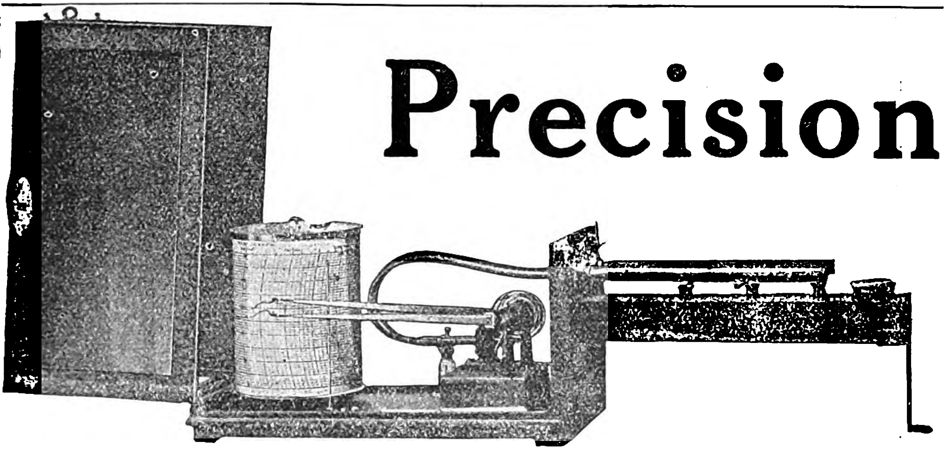

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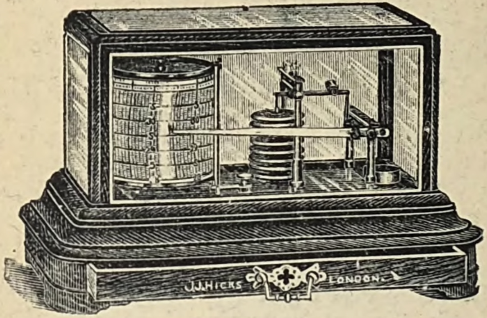

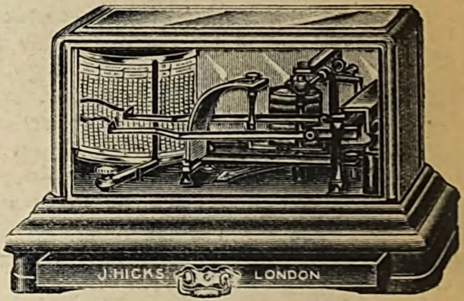

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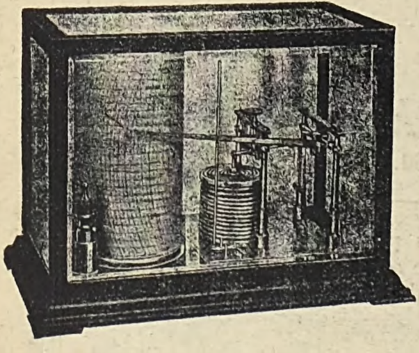

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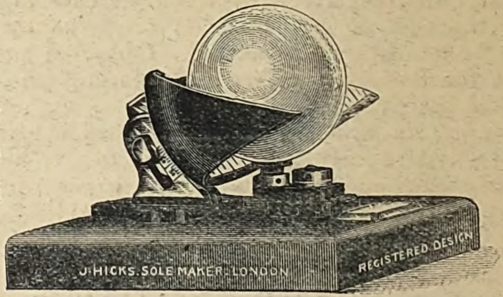
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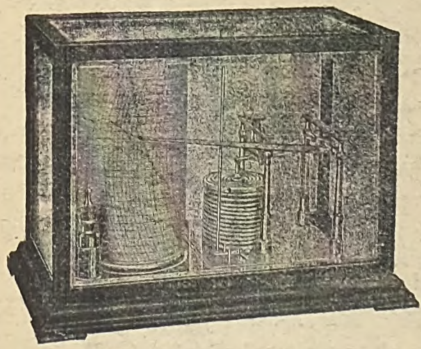

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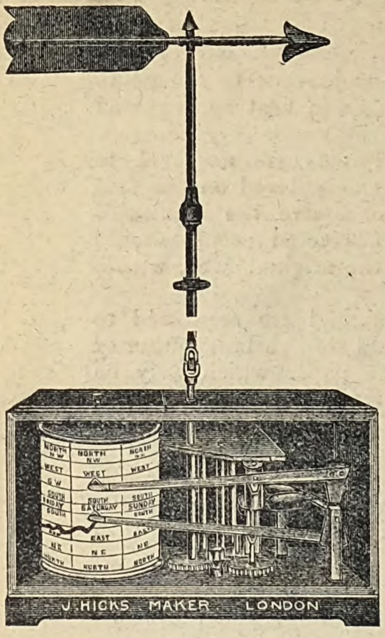

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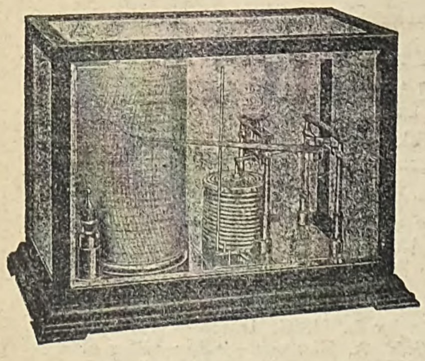

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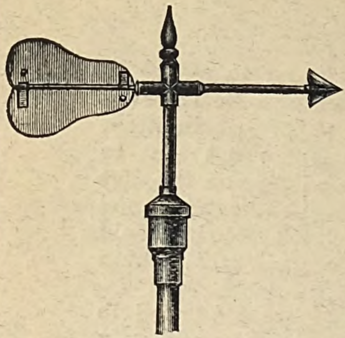

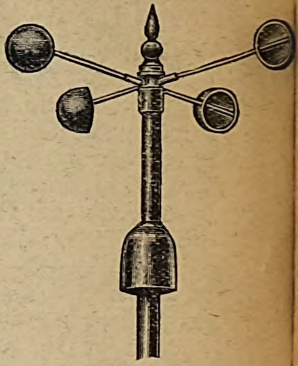

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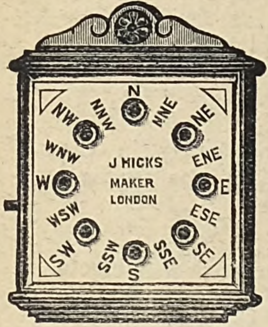

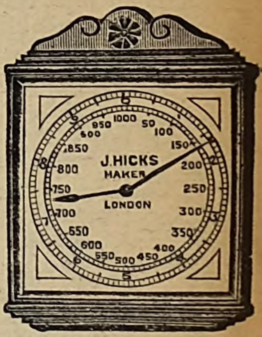

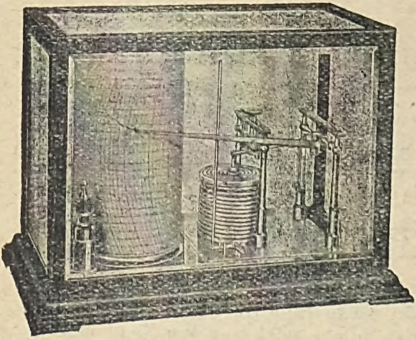

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